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DEPARTMENT OF BUSINESS
AND ECONOMIC DEVELOPMENT

ENVIRONMENTAL REVIEW

500 MW GEOTHERMAL DEVELOPMENT

PUNA DISTRICT, ISLAND OF HAWAII

STATE OF HAWAII
1959
UA MAU KE EA O KA AINA I KA PONO

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AND ECONOMIC DEVELOPMENT

ENVIRONMENTAL REVIEW

500 MW GEOTHERMAL DEVELOPMENT

WITHIN THE THREE GEOTHERMAL RESOURCE SUBZONES OF THE KILAUEA EAST RIFT ZONE PUNA DISTRICT, ISLAND OF HAWAII

MARCH 1989

STATE OF HAWAII
1959

Prepared
for the
Energy Division
Department of Business
and
Economic Development

by
MCM Planning
703 Honua Street
Honolulu, Hawaii 96816

PREFACE

This environmental review is based on information available in the existing literature on the subject. It identifies types of impacts that could be expected in a development of this magnitude and suggests general mitigating measures. Specific environmental impacts would have to be determined as each plant complex is designed and constructed. If monitoring of a plant's operations reveals adverse impacts to the environment, additional mitigating measures would have to be instituted.

The report was prepared for the Energy Division of the State Department of Business and Economic Development by MCM Planning, in association with the following firms:

Char & Associates	Flora and Fauna
Community Resources, Inc.	Social Impact Analysis
Cultural Surveys Hawaii	Archaeology
Dames & Moore	Geology, Soils, Air Quality, Hydrology, and Noise
Decision Analysts Hawaii, Inc.	Economic Analysis and Impacts
KRP Information Services	Policies and Plans
R. M. Towill Corporation	Technical Description, Infrastructure

We would like to thank Mr. Jerry Lesperance of the DBED Energy Division, Mr. Rod Moss of True/Mid-Pacific Geothermal Venture and Mr. Ralph Patterson, formerly of Puna Geothermal Venture, for their technical assistance in preparing this report.

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PART I: INTRODUCTION

A. BACKGROUND

Hawaii presently relies upon imported petroleum fuel to supply 90 percent of its total energy needs, making the State vulnerable to sudden shortages in supply or escalations in the price of this diminishing source of energy. A major policy of the Hawaii State Plan is to increase energy self-sufficiency (Section 226-18, Hawaii Revised Statutes). As stated in the State Energy Functional Plan (DPED, 1984a), it is a priority objective for the State to "Accelerate the transition to an indigenous renewable energy economy by facilitating private sector activities to explore supply options and achieve local commercialization and application of appropriate energy technologies."

Geothermal heat as an alternative energy source was first explored for commercial use in Hawaii in 1961, when four test holes were drilled by a private company in the Kilauea East Rift Zone, Puna District, Island of Hawaii (Figure I-1). Twelve years later, a research well was drilled at the Kilauea summit to a depth of 4,141 feet. The temperature of fluids at the bottom of the well was 275 degrees F and there were indications of much higher temperatures at greater depths. At approximately the same time, the University of Hawaii started an exploration program for a second exploratory well. A 6,540 foot well was drilled in 1976 in the Kapoho Section of the Kilauea Lower East Rift Zone and named the Hawaii Geothermal Project Abbott (HGP-A). A 3-megawatt wellhead generator was installed in 1981 that regularly provides enough electricity to the Big Island utility to meet the demands of 2500 homes. The State of Hawaii anticipates that by the year 2007 up to 500 deliverable megawatts (MW or MWe) of geothermal-generated electricity could be transmitted from the island of Hawaii to the islands of Maui (up to 50 megawatts) and Oahu via a submarine cable system.

In recent years the State Legislature adopted a number of bills to facilitate the orderly development of geothermal energy in Hawaii. Act 135, SLH 1978, granted geothermal developers a favorable (one-half of one percent) general excise tax rate on the sale of energy produced from geothermal resources. Act 296, SLH 1983, the Geothermal Resource Subzone Act (amending Chapter 205, Hawaii Revised Statutes), provided for the designation of geothermal resource subzones wherein proposals for geothermal development could be considered by appropriate State and County

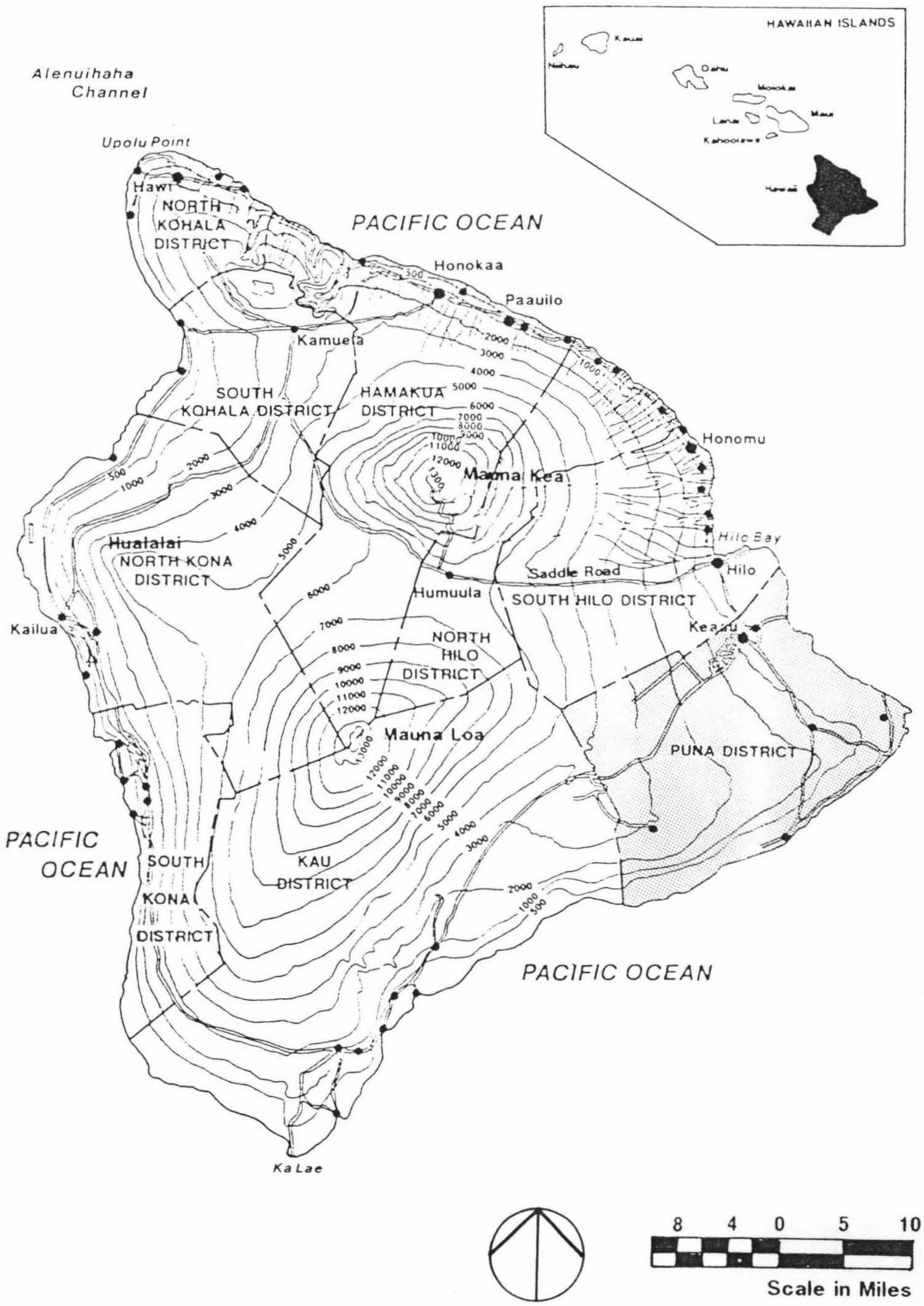


Figure I-1
LOCATION MAP

permitting agencies. This act authorized subzones to be established by the Board of Land and Natural Resources (BLNR) in areas of significant geothermal resources where the potential positive environmental, economic and social benefits of the development to the State as a whole outweigh the potential negative environmental and social impacts. Act 138, SLH 1985, requires the BLNR to fix the payment of royalties to the State for the use of geothermal resources at a rate which will encourage new and continued geothermal production and development. Act 237, SLH 1985, designates the Department of Planning and Economic Development (DPED) with the task of facilitating and coordinating actions by State agencies and the processing of permits. Act 301, SLH 1988 provides for a coordinated permitting process involving the various state and county agencies that must approve the development of geothermal energy and designates the Department of Land and Natural Resources (DLNR) as the lead agency.

B. PURPOSE OF THIS REPORT

The establishment of a geothermal industry in Hawaii requires a sound understanding of the environmental impacts of geothermal development and suitable regulations to protect the environment and the health of the populace. This comprehensive review, synthesis and evaluation of existing environmental information has been undertaken in order to assess the potential environmental effects of generating 500 deliverable megawatts of geothermal energy within the Kilauea East Rift Zone.

An environmental assessment for an interisland cable system that would deliver a net 500 MW of geothermal-generated electricity to Maui and Oahu from the Kilauea East Rift Zone was recently prepared by Parsons Hawaii under the Hawaii Deep Water Cable Program (Parsons Hawaii, 1987). This environmental review is intended to complement the interisland cable assessment and possibly form the basis for a future Environmental Impact Statement (EIS) for the generation and transmission of electricity from the Puna geothermal resource subzones (GRS). At the least, this comprehensive environmental review should form the basis for future environmental impact analyses of individual developments as they prepare to come on-line.

C. GEOTHERMAL RESOURCE POTENTIAL

For the purpose of this environmental review, the areas considered as potential sources of geothermal power are the three GRS within the Kilauea East Rift Zone on the Big Island of Hawaii. Specifically, they are: (1) the Kilauea Middle East Rift GRS (9,104 acres); (2) the Kamaili Section of the Kilauea Lower East Rift GRS (5,530 acres); and, (3) the 7,350-acre Kapoho Section of the Kilauea Lower East Rift GRS (Figure I-2).

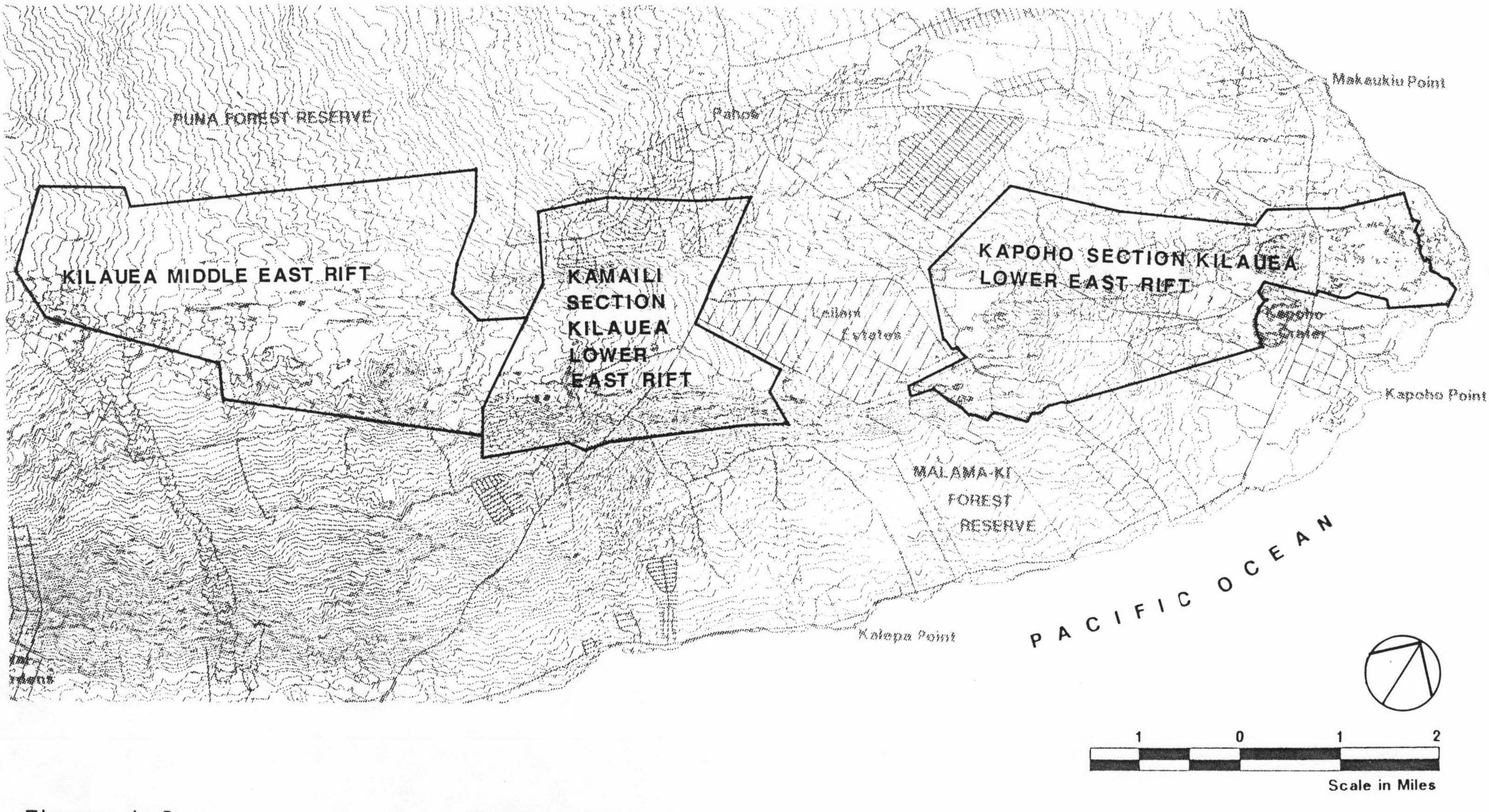


Figure I-2

GEOTHERMAL RESOURCE SUBZONES

The successful operation and generation of electricity by the HGP-A plant confirmed the resource potential of the east rift zone. In addition, numerous geophysical, geological, and geochemical studies of the east rift zone that have been performed in recent years further demonstrate the resource potential of the area.

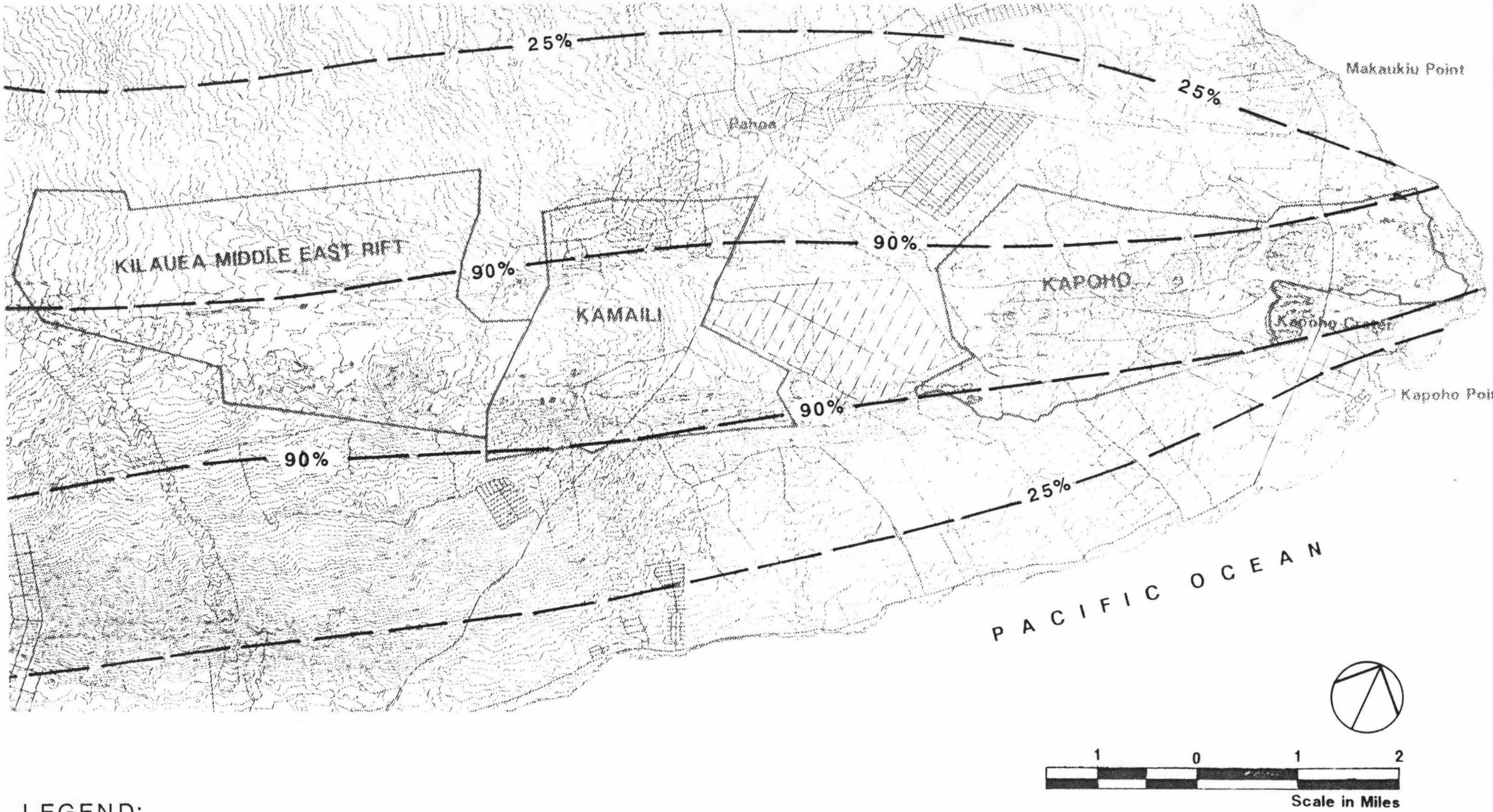
Studies conducted by Holcomb (1980) have shown that the surface volcanic expressions of the entire east rift zone indicate little, if any, change in the geologic character of the rift zone from upper to lower elevations. From these studies it is presumed that the subsurface character will not be much different between the upper and lower portions of the rift zone (Niimi, 1985).

As indicated by DLNR (1985) "Currently available geotechnical data indicated the presence of a geothermal resource along the entire Kilauea East Rift Zone. The assessment of geothermal resource potential was based on a qualitative interpretation of regional surveys based on the following types of data: groundwater temperature; geologic age; geochemistry; resistivity, infrared, seismic, magnetic, gravity and self-potential surveys; and exploratory drilling. The evaluation of these data indicated that the potential for a geothermal resource on this rift zone was greater than 90 percent through its entire length." Figure I-3 delineates the estimated percent probability of geothermal resource potential in the GRS areas of the east rift zone. High rainfall on the eastern portion of the Island of Hawaii, and possibly seawater intrusion below the area, provide a large source of water to supply the geothermal system. Further, DLNR (1985) concluded that "...no single geothermal exploration technique, except for exploratory drilling, is capable of positively identifying a subsurface geothermal system...".

Data on the production potential of the subzones is necessary to demonstrate to private developers of the interisland cable that sufficient geothermal resources are present on the Big Island to justify proceeding with the costly commercial submarine cable program.

D. OVERVIEW OF THE GEOTHERMAL ENERGY TO ELECTRICITY CONVERSION PROCESS

To understand the potential of geothermal energy it is necessary to understand what is happening beneath the surface of the land. Deep in the earth's crust (usually 20 miles) is a mass of molten rock called magma. In some areas, such as Hawaii this magma is closer to the surface due to crustal fractures and it heats the layers of rock above it. If underground water is present, a geothermal reservoir is created. It is this



LEGEND:

90% PERCENT PROBABILITY OF GEOTHERMAL RESOURCE POTENTIAL

Figure I-3

ESTIMATED PERCENT PROBABILITY OF GEOTHERMAL RESOURCE POTENTIAL

SOURCE: MODIFIED FROM DLNR, 1985.

liquid-vapor reservoir which is tapped to provide the source for geothermal-generated power.

The production wells and pipes bring the geothermal fluid to the separator for flashing; a process that separates the steam from the fluid or brine. The majority of the dissolved minerals remain in the brine and any gasses remain in the steam fraction. The separator discharges steam into the steam gathering system. The steam gathering system then transports the steam to the turbine in the power plant. The brine gathering system is responsible for the transportation and disposal of the brine into the injection wells.

Electricity is generated in the power plant through the use of a steam turbine coupled to an electric generator. The turbine converts the energy of the steam into electricity. The steam from each turbine exhausts into a steam condenser/heat exchanger which condenses the steam. The condensate drains from the top of the condenser into the hotwell in the bottom. The non condensable gases and uncondensed steam are then discharged into a gas abatement system (Figure I-4).

E. CONCEPTUAL DEVELOPMENT SCENARIO

1.0 Development Concept

The generation of 500 deliverable MW of geothermal energy on the Big Island for transmission to Maui and Oahu via the interisland cable would involve a number of interconnected components, including: (a) power plants, which utilize standard steam-driven turbine generators, steam condensers, and pollution control devices; (b) production wells and a network of surface pipes to deliver the steam to the power plants; (c) surface piping to deliver water (which has been condensed from steam) from the plants to injection wells; (d) injection wells to dispose of this water; (e) surface piping to deliver brine from the separators to injection wells; and, (f) overhead AC power lines to deliver the electricity produced to an AC-to-DC converter station.

Within each GRS, surface areas for development of geothermal resources would be selected on the basis of previous surveys, exploration, surface expressions that indicate earlier volcanic activity, geothermal and reservoir analysis then with some attention to the following factors: (a) avoidance of developed residential or environmentally sensitive areas; (b) the slope of the surrounding terrain; and, (c) avoidance of those sections of the active rift zone with significant faults and cracks. Power plants would generally be located close to the wells with concern about volcanic activity, etc.

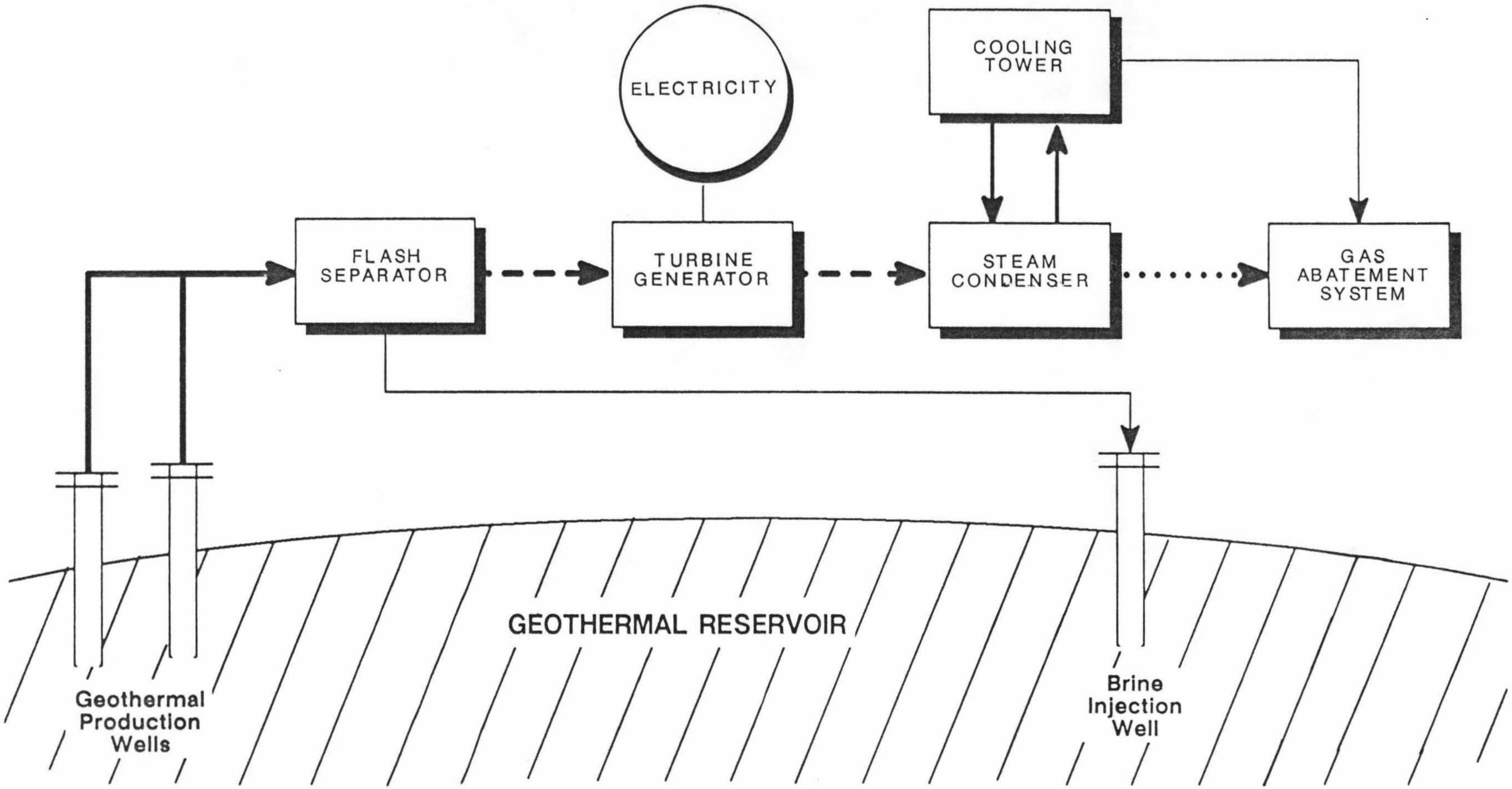


Figure I-4
SYSTEM FLOW DIAGRAM

SOURCE: MODIFIED FROM THERMAL POWER (1987).

Power plant sites would be located within two miles of the furthest well pad supplying steam to the plant in order to limit costs and to prevent unacceptable heat losses in the movement of the hot fluids to the plant. Service roads and transmission pipelines would be constructed between the well sites and the power plants. Buffer zones would separate plant, well and road activities from adjacent property boundaries.

The electrical power generated would be transmitted as AC from the power plants via 138-KV transmission lines to a common Converter Station where it would be converted into DC and then exported via a 300-KV interisland transmission line to the termination station of the interisland cable.

2.0 Basic Assumptions

The review and evaluation of potential environmental effects associated with the conceptual development scenario presented in this report, is based on the following basic assumptions:

- <u>Delivered capacity is assumed to be 500 MW.</u> Generating capacity would be somewhat higher, up to a total 600 MW, in order to account for transmission line losses, power plant parasitic loads, and maintenance downtime.

- A conceptual geothermal system, consisting of four development areas within each GRS (each area representing approximately 50 MW of power generation), was used as the basis for evaluating environmental effects (Figure I-5).

  (Although actual development would probably differ from the concept presented in this report (e.g. the power plants within each subzone could range in capacity from 12.5 MW to 55 MW), the conceptual layout presented in Figure I-5 allows each subzone to be assessed on more or less similar development assumptions and provides the basis for evaluating a worst case scenario for air quality and other critical environmental factors).

- For purposes of this analysis, power plant sites are located a minimum of one kilometer apart. Preliminary air quality modeling, using conservative parameters, suggested that this spacing was necessary in order to maintain ambient air quality within each subzone.

- The underground reservoirs in each GRS are assumed to be uniformly distributed. The actual location of geothermal reservoirs and the economic production potential of the resource, however, can only be determined by deep drilling and by testing each successful well. Inherent in this process is preliminary exploration which is necessary in

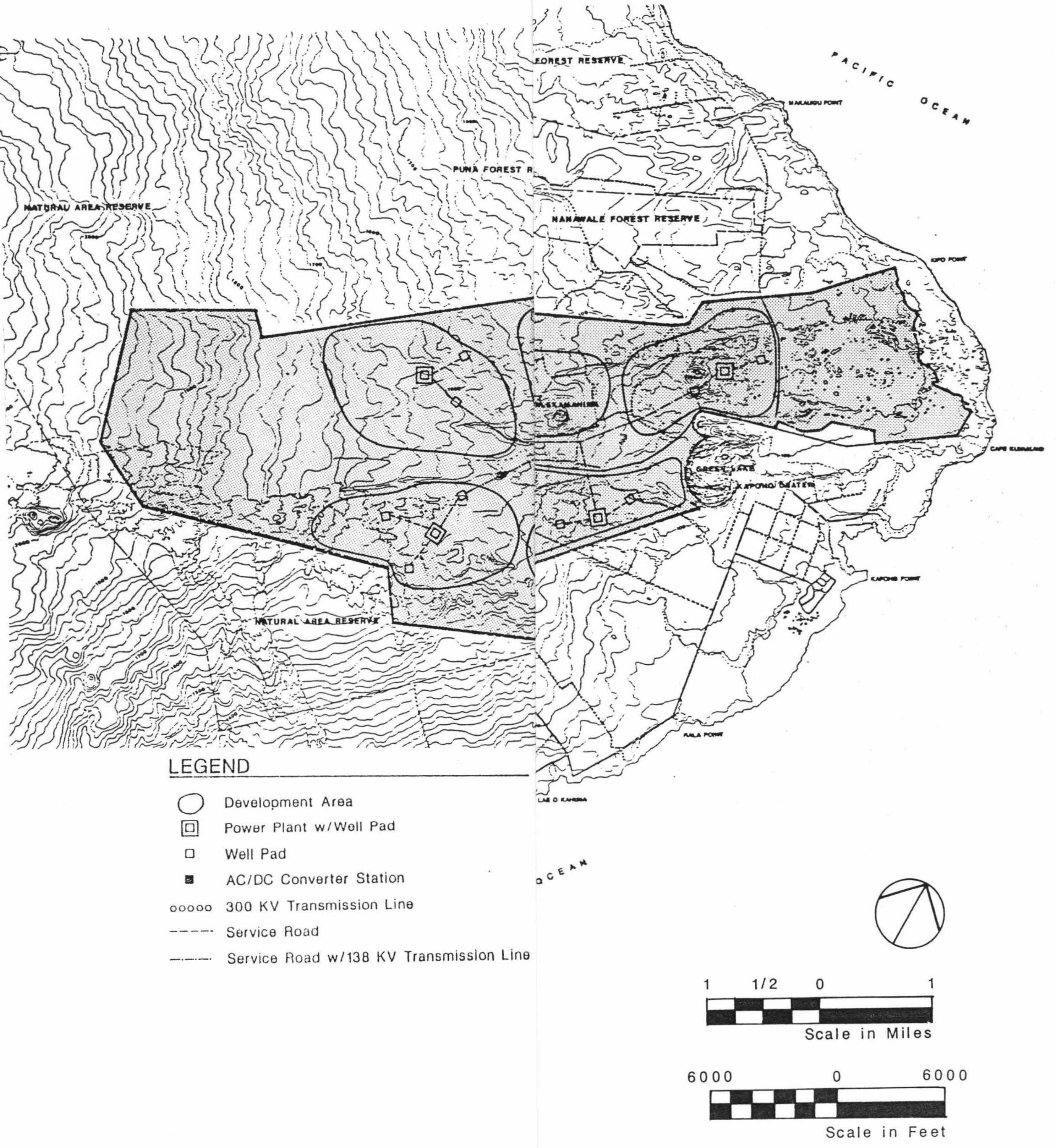


Figure I-5

CONCEPTUAL GEOTHERMAL

order to fully define the extent and characteristics of geothermal reservoirs.

- In addition to a power plant, each development area would have three or four well pads connected by service roads; each pad would contain about three but up to six wells. (The actual pattern of well pads would evolve with time as productive geothermal resource areas are identified and developed).

- The first power plant is projected to come on line in 1995; additional power plants would become operational at a rate of approximately one per year. Development would begin three years before the first plant becomes operational; construction is assumed to span about a 14-year period. (The economics and specific phasing of this geothermal development are discussed in Section III).

F. PUBLIC INVOLVEMENT

During the geothermal subzone assessment process, conducted pursuant to Act 296, SLH 1983, various channels and methods of community input were involved to discuss the social, environmental and economic impacts of geothermal development on them and on the State as a whole. These channels included agencies, public informational meetings, political representatives, regulatory agencies, public and contested case hearings.

Throughout the process, from the enactment of Act 296 to the Proposal for Designating Geothermal Resources by BLNR, public comments and participation were encouraged. Eleven public informational meetings were held on the islands of Hawaii and Maui. The objective of these meetings was to open lines of communication between the public and the DLNR. In addition, on July 29, 1985, DLNR mailed letters to concerned parties requesting written comments and information on the proposed geothermal resource subzones. The meetings reported the most likely locations of geothermal resources and focused on the identification of impact issues.

An environmental review workshop, sponsored by the Puna Community Council, to discuss the proposed 500 MW geothermal development was held in Pahoa on November 9, 1988. Appendix A provides an overview of the workshop.

G. SUMMARY OF FINDINGS AND RECOMMENDATIONS

o General

Geothermal wells should be developed in areas of highest resource potential and least volcanic hazards potential. In general, plant sites should be located on higher ground, if practicable, to minimize susceptibility to volcanic hazards. Buffer zones should separate plant, well and road activities from adjacent property boundaries.

Construction at any given plant or drill site should be preceded by planning and ground surveys. If located in a potentially environmentally sensitive area, the proposed site should be surveyed by archaeologists and biologists. Site locations should then be adjusted to avoid archaeological sites and endangered or unique species of flora and fauna.

Service roads within the plant and wellfield areas should be sited to: avoid volcanic hazards (geophysical faults and cracks); avoid areas identified to include endangered species; avoid residential communities; and, minimize the high cost of construction. The service road corridors, however, would need to be essentially straight, in order to accommodate power transmission lines. A botanist should be consulted before vegetation in forested areas is cleared for the road and transmission line corridors; large trees should be retained if possible.

o Air Quality

Dispersion modeling undertaken for this environmental review showed that development of 500 MW of geothermal power in the Puna region would result in air quality within applicable standards or increments. Each of seven H_2S emission control technologies examined yielded acceptable impacts in relation to the proposed Hawaii H_2S increment of 35 ug/m^3.

Other pollutants, such as SO_2 and PM_{10}, were found to not be significant factors for siting of geothermal power plants in the Puna geothermal region. PM_{10} emissions would be a significant factor only if the cooling tower makeup water contained total dissolved solids (TDS) concentrations that greatly exceeded the concentration of 15 ppm(w) used in the analysis.

Although short-term upset emissions are exempt from the proposed regulations, air quality impacts resulting from these conditions were also examined. Modeling results indicated that impacts could exceed the proposed H_2S increment of 35 ug/m^3 but remain below the proposed standard of 139 ug/m^3. Health risks associated with this highly unlikely upset condition would be negligible.

While the overall modeling results indicate only a very slight potential for significant H_2S air quality impacts (under the proposed State of Hawaii maximum allowable H_2S emission scenario or upset conditions), several assumptions used in the H_2S emission calculations and dispersion modeling have lead to estimated H_2S impacts which are probably much greater than would actually occur. H_2S emission calculations were based on the maximum observed H_2S steam concentration. Based on data from geothermal wells in the region, steam H_2S concentrations in some areas could be lower than the maximum value used in this assessment.

Under normal operating conditions, H_2S concentrations would be expected to remain below odor thresholds for most emission scenarios. Under worst-case upset conditions, H_2S concentrations would have the potential to exceed the odor threshold, but these upset conditions are highly unlikely.

o Noise

Noise abatement mitigation measures should be applied where feasible to avoid potentially significant noise impacts. Several noise mitigation measures that should be considered for future projects.

<u>Drilling Rig Noise</u>: use residential-grade exhaust mufflers; place or construct acoustic enclosures around drill rig engines and any other noisy equipment; silence engine radiator air inlets and outlets; use effective rock muffler during flow testing and well workover activities; and, schedule excessively noisy activities, such as flow testing and well workover activities, during daylight hours.

<u>Construction and Plant Decommissioning Noise</u>: use highly efficient engine exhaust mufflers on all construction equipment and auxiliary equipment; set heavy equipment backup alarms to near minimum legal limit; and, limit all significant construction activities to daylight hours.

<u>Operation Noise</u>: insulate major pipes and valves with acoustically effective material; install silencers or rock mufflers on all pressurized steam outlets, when feasible; acoustically insulate steam injectors; orient plant layout to shield residents from noise and utilize landscaping to attenuate sounds emanating from plant operations; use state-of-the-art quiet fans, motors, and baffles for cooling towers; use acoustical insulation and enclosures for turbine generator; and, schedule all routine

maintenance during daylight hours and avoid nighttime unscheduled maintenance where possible.

Implementation of these mitigation measures would help to avoid significant noise impacts on nearby residential and recreational areas resulting from drilling, construction, and operation noise.

o Geological

Because the GRS are located in the most active rift zone on the island, it is extremely improbable that removing the relatively small amount of heat energy needed to meet the power plant requirements would have a significant cooling effect on the geothermal resource, which is periodically renewed by new magmatic movements. It is also improbable that the reservoir will dry out because of the highly permeable rock surrounding it, the high rainfall in the Puna District, and the hydrologic conditions of the island. Leakage from the overlying groundwater, combined with reinjection, would replace any net losses of geothermal fluid.

o Geologically Related Hazards

Critical equipment should be designed to Seismic Zone 4 requirements, which exceeds the State of Hawaii Zone 3 requirements. The axis of the generator should be aligned approximately parallel to the rift system. Abatement procedures against volcanic eruption hazards consist of: locating all major facilities north of the active rift zone (the southern part of the ERZ), preferably on high ground; constructing barriers on the uphill side of the facilities; placing major facilities on raised platforms; and, placing critical components in buried cellars that lava cannot enter.

There has been some concern expressed regarding the possibility of geothermal development causing or inducing volcanic or seismic activity. Because of the basic structure of Hawaiian volcanoes and the general progressive pattern of eruptions, drilling into a geothermal reservoir or into a magma body itself would not in any way be sufficient to trigger an eruptive outbreak on the flank of the volcano or at its summit.

It is considered highly unlikely that drilling or brine withdrawal and reinjection in Hawaii's geothermal systems could cause seismic activity of any perceptible magnitude. In Hawaii, the subsurface rocks are self-supporting basalts already saturated with water. Injection of water into the subsurface environment, as may be required for brine disposal, would simply displace water already there and would not act as an added lubricant. Recently, however, scientists at Hawaii Volcano Observatory (HVO) have hypothesized that earthquake activity in the HGP-A region may be due to movement along a fault (the transverse break) that crosses the Lower East Rift Zone in this area. If this is the case, geothermal development could have some effect on seismicity, perhaps by inducing fault movement.

o Groundwater Resources

Impacts to groundwater during exploration and development phases are expected to be limited and of short duration. In order to establish a reference base for water quality, groundwater in the vicinity of each well should be tested during drilling. Clearing and construction activities should not be expected to have any impact on surface or groundwater quality within or adjacent to the project areas. Developers should establish procedures to minimize the effects of accidental spills of materials such as oil and gasoline.

During normal drilling operations geothermal wells are drilled past groundwater aquifers and well well casings are set and cemented through subsurface formations containing the basal water lens. All drilling, casing installation, maintenance and abandonment of geothermal wells and reinjection wells are regulated and would be monitored to protect the groundwater aquifer.

Surface and groundwater are likely to be impacted to some extent should unexpected events develop during drilling operations. The installation of "blowout" preventers on all well heads would mitigate this effect. The potential for contaminating surface or groundwaters is considered minimal because regulations governing drilling of deep geothermal wells are stringent and are intended to prevent such occurrences.

Disposal of spent geothermal fluids would be accomplished by reinjecting the spent brines and other solids back into the reservoir. The volume of brine to be reinjected in a 500 MW development is estimated to be approximately 2,550 gpm. This rate of injection could be readily accepted by the deep subsurface formations without excessive hydraulic response. Reinjection could help to prolong the life of the geothermal resource by returning unused heat to the resource zone. At this time, however, the pace of magmatic activity is such that the geothermal resource, for practical purposes, might be considered self renewing.

In the Kapoho Section of the Kilauea Lower East Rift Zone, the groundwater has been found to be brackish and at temperatures of 90°F or higher; this water is generally unsuitable for domestic or agricultural use. Should the constituents of the geothermal fluids be found, by testing, to be benign or similar to brackish water existing in the vicinity of the wells, disposal of the effluent by reinjection should not impact groundwater resources in the area.

There is very little site specific groundwater information available for the Kilauea Middle East Rift GRS and Kamaili Section of the Kilauea Lower East Rift GRS. Water sampling and well monitoring should be performed during well installation to determine the hydrological characteristics of the local groundwater and of all aquifers encountered during drilling. Monitoring wells downgradient from geothermal development activity would increase the probability of early detection of any potential undesirable effects on groundwaters.

o Flora and Fauna

Intensive, on-site inspections to determine the presence or absence of threatened and endangered species as well as forest quality should be required for each plant and drill site, including access roads. Site specific mitigation measures addressing environmental concerns then need to be presented. Monitoring of each specific site should begin during the initial exploration phase before development commences and continued during the construction and operational phases.

Probable environmental impacts on biota and mitigation measures include:

<u>Direct loss of habitat and destruction of native plant communities as a result of land clearing for geothermal facilities</u>: Siting of roads and well pads during the exploration phase, as well as transmission lines, power plants and other facilities during the later construction and operational phases, on less sensitive areas such as recent lava flows and in areas dominated by introduced species can lessen the impact on the native biota. Highly sensitive areas which are dominated by native species such as the 'ohi'a-a(1) and 'ohi'a-a(2) forests should be avoided as much as possible. Early on, the biologists should be working closely with the engineers and planners in identifying and evaluating potential alignment corridors and drilling sites. When road alignments and drilling sites have been selected and staked out, the biologists should conduct a survey on and adjacent to these areas. Realignment and relocation of drilling sites are recommended if threatened or endangered species or sensitive native plants and animal communities are encountered

<u>Invasion of cleared areas by weedy, introduced species</u>: Disturbed sites such as unpaved road margins and open roadsides are prime sites for weed establishment; these weedy species move out into small openings in the forest, occupying space once utilized by native species. Invasion by introduced plants also reduces the habitat quality for native birds and invertebrates thus affecting the distribution of these organisms.

Among the recommendations for minimizing spread of invasive weedy species are: limiting vegetation removal to only that which is essential; if possible, all transmission lines should be constructed along existing road corridors to minimize the amount of vegetation removed; using soil and rocks from high points in the project area for additional surface or fill material rather than bulldozing them into ridges at the sides of roads or hauling in fill material from outside of the project areas; continual monitoring of developed areas for weeds and appropriate and environmentally compatible methods of weed control for these areas; revegetation with native material as soon as possible.

Long-term effects: Air emissions and noise from day-to-day operations are the primary concerns when discussing long-term effects. The principal mitigation measures include effective abatement systems and design features that can be incorporated into the production and energy conversion systems. Air emissions are controlled to meet federal and state standards designed primarily on the basis of human health requirements. Periodic environmental monitoring of these sites will be necessary so that cumulative effects of geothermal development activities on the biota can be identified fairly early on.

Venting of a well for short periods could disrupt the native avifauna. Relatively high noise levels would occur within a one-mile radius of a well during venting. If endangered species such as 'I'o are known to be present nearby, mitigation measures should include that such activities be conducted during the non-breeding season of the particular species.

Compaction of soils associated with construction, as well as standing water in abandoned machinery and used materials associated with operation activities, may provide breeding sites for mosquitoes that are vectors of certain avian diseases. All sites should be periodically checked to see that drainage remains unimpeded, particularly in areas with high native bird populations.

Future biological surveys should include invertebrate studies, especially in areas containing more or less intact native forests.

There is also a need for enforcement and follow up of mitigative measures or recommendations agreed upon by the geothermal developers and the permitting government agencies. One method would be for the geothermal developer to set aside funding for follow up monitoring of recommendations.

o Archaeology

Although it is clear from historical records and 19th Century Maps that the upland of Puna within the three geothermal resource subzones were utilized by ancient Hawaiians, the actual number of recorded and potential site areas are limited. This could be a result of the lack of systematic survey in the areas and a number of sites may be present, but are as yet undiscovered. However, it is certain that large areas of the lava lands are devoid of archaeological remains, particularly in the more inland sections. Most of the areas that would have been within the upland planting zone have been inundated by recent lava or saw long-term use in sugar cultivation.

All areas covered by lavas postdating 1800, particularly those areas covered by very recent flows have no archaeological potential. There are, however, small <u>kipuka</u> areas within many of these flows which have the potential for containing archaeological sites.

Lava tubes were preferred dwelling places and sources for fresh water in ancient Hawai'i. These features are difficult to identify in ground surveys and there could be many undiscovered tubes on the older flow surfaces, including cane lands within all three subzones.

Many sites within older flow surfaces may be as yet undiscovered. As a general archaeological rule the older the flow surface, the more likely sites are to be present. Similarly the older the flow surface, the heavier the vegetation and the greater the difficulty in finding archaeological sites either from the air or the ground. Given the immense land areas (over 21,000 acres) and lack of access within the three subzones a systematic archaeological survey of older flow surfaces is clearly out of the question. Mitigation of impact on potential site areas should be concerned only with specific potentially sensitive areas to be affected by well sites, power lines and roads on a project by project basis.

No further archaeological work should be required for facilities or portions of facilities located on recent lava flows. The boundaries and routes of wells, power lines and roads to be located in areas of older flows, particularly near known archaeological site areas, should be land surveyed and staked in the field and archaeologists should perform reconnaissance surveys of these specific areas before construction. In some heavily vegetated areas bulldozer grubbing should be permitted in conjunction with the archaeological reconnaissance in direct coordination with the field archaeologist. In unvegetated areas of the proposed facilities helicopter reconnaissance of surveyed and staked localities would be a complement to on-the-ground reconnaissance. If archaeological sites are found within the proposed power lines, roads or well sites during reconnaissance surveys, the facility location should be readjusted to avoid these sites.

o Visual impact analysis

In the Kilauea Middle East Rift GRS the visual impact of geothermal development from Highway 130 at Queens bath is insignificant because of distance and topography and the view is blocked by dense vegetation. The visual impact from the closest national park boundary to the subzone boundary is also insignificant because of the distance and dense vegetation. Development in the subzone would have very low visual impact; the entire GRS is not visible from the road because of topography and dense vegetation.

In the Kamaili Section of the Kilauea Lower East Rift GRS development would be mauka of Highway 130, so there would be no obstruction of views to the ocean. Visual impact could be low if the facilities were sited so that they were hidden by Iilewa crater; in addition, dense vegetation blocks the sight line from the highway (130). Visual impact of the AC/DC converter station would be low because it is in dense woodland forest vegetation. The 138-KV transmission line would be visible if it crosses Highway 130, otherwise, the sight line would no be affected by power plants or converter station due to existing dense vegetation. The Leilani Estates perimeter road is 1500 feet away from the conceptual 138-KV inter-zonal transmission line, however, because of heavy vegetation it should be virtually invisible from residences in the subdivision.

In the Kapoho Section of the Kilauea Lower East Rift GRS there would be low visual impact from Highway 132 due to topography and existing vegetation. Even the transmission lines would be invisible from this sight line, therefore there would be no mitigation necessary. As viewed from Highway 137, geothermal facilities would be highly visible due to the surrounding lava field terrain. A vegetation screen around the power plant perimeter would minimize the visual impact.

Visual impact from Highway 132, where transmission lines cross the highway, would be high. Elevations higher than power plants and sparse vegetation in the area would result in very high visual impact. Vegetation screens along the perimeter of the power plants would minimize visual impact, however, because of the terrain the facilities would not be hidden from view and thus visual impact would still be moderate.

o Socio-economic

During the construction phase, geothermal power is expected to directly support 575 people and 215 homes, and directly and indirectly support a total of 1,430 people and 530 homes. Upon full operations, 480 people and 180 homes would be directly supported, and 1,570 people and 580 homes directly and indirectly supported.

Social impacts generated by the development itself and by increased population could be mitigated through the use of state-of-the-art abatement technology; through careful planning of sites and routes; and through community dialogue and information programs. Community relations efforts to offer the public reassurance could include: a 24-hour telephone "hotline" on which area residents' complaints are logged, along with development staff available at all times to respond to questions and complaints; educational programs about geothermal energy and volcanism; maintaining a seismic monitoring station in Lower Puna, and providing information about seismic activity noted; and, developing and demonstrating contingency plans for geothermal plants in the event of eruptions or lava flows, to show the public that geothermal development does not make catastrophes less controllable. In addition, community outreach programs can be extended to monitor and alleviate social problems involving newcomers brought by the project.

The longer-term impacts of the project would be experienced as minor annoyances or major intrusions in residents' experience of their region, depending on: the distance from public roads of power plants and sources of noise and odor due to geothermal operations; the extent of the area which would be restricted from community access and the length of time that access would be barred; and, whether or not fences and other signs of restricted access are highly visible from roadways -- fence materials and coloring could be chosen to blend in with the surrounding forest and to minimize the appearance of industrial development.

The less noticeable the project is, the less disruption of regional character is to be expected. Also, through community dialogue, some members of the community can come to recognize that geothermal operators are concerned for the environment and residents' safety.

o Impacts Anticipated by Hawaiians in Puna

The Puna Hui Ohana survey respondents saw geothermal development as having large-scale consequences. Some impacts were expected by many respondents to be good or bad. In other cases, the response was mixed, with many respondents expecting negative impacts, and a few more respondents expecting positive ones:

Hawaiians in Puna anticipate clear-cut local impacts of geothermal development. They are concerned with changes in their economy, and with access to land resources. They are also concerned with the general character of their region, as are other Puna residents.

Many Hawaiians elsewhere are concerned with the State's responsibilities and attitudes towards Hawaiians as a group -- geothermal development is only one of several topics where the State's commitment to Hawaiian citizens can be measured. They do not anticipate particular impacts so much as they look for a general policy of respect towards Hawaiians.

The Pele practitioners anticipate grave impacts of geothermal development on their god and on themselves. There is no evidence that many support their contention that Pele's well-being and Hawaiian identity are endangered by geothermal development.

The State and geothermal developers can respond to some of the concerns of Hawaiians in Puna in several ways: job training programs and programs to encourage the hiring of locally available labor can make employment available to Puna Hawaiians, among others; archaeological surveys and recording, done before drilling and construction, can insure that disruption of traditional sites will be minimized; and, botanical inventories of the geothermal subzones in order to identify medicinal and other traditional resources and to assure that supplies of such resources remain outside the areas where geothermal operations are planned.

H. ORGANIZATION OF THE ENVIRONMENTAL REVIEW

This report is organized in the following manner:

- Part I gives an overview of the geothermal development, describes the development concept and assumptions upon which this environmental review is based, discusses the potential resource and public involvement and presents a summary of findings and recommendations.
- Part II discusses the technical characteristics of a generic 500 MW geothermal development.
- Part III presents an economic analysis of a 500 MW geothermal development.
- Part IV describes the physical environment in the vicinity and discusses potential impacts and mitigation measures of the proposed development.

- Part V describes the biological resources in the vicinity and discusses impacts and mitigation of the proposed development.

- Part VI describes the archaeological and cultural resources in the vicinity and discusses the impacts and mitigation of the proposed development.

- Part VII describes the land use, infrastructure, public services and visual characteristics of the Puna area and evaluates project generated impacts on these factors.

- Part VIII discusses the social and economic characteristics and public concerns of the proposed geothermal development and affected regions, evaluates potential impacts and proposes mitigating measures.

- Part IX discusses policies and plans that relate to the proposed development and lists permits required for each individual project.

- Part X is literature cited and personal communications.

PART II: TECHNICAL DESCRIPTION

A. DESIGN, CONSTRUCTION AND OPERATION OF GEOTHERMAL WELLS

The following description is excerpted from Revised Environmental Impact Statement for the Kahauale'a Geothermal Project (Towill, 1982a).

1.0 Drilling

The drilling, operation and maintenance of geothermal wells are closely regulated by the State regulations, "Rules on Leasing and Drilling of Geothermal Resources", DLNR Administrative Rules, Title 13, Chapter 183.

Ideally, geothermal wells would be developed in areas of highest resource potential and least volcanic hazards potential. Prospective well pads would be evaluated by these factors and by other considerations, such as: the need to maximize the exploration/development effort within the GRS while at the same time minimizing the amount of drilling required; and, the need for appropriate spacing to enhance the production life of discovered reservoirs.

Each well pad would consist of a cleared rectangular area, approximately 500 feet in length by 300 feet wide, with a 60-foot wide perimeter for safety and security, and would encompass approximately two to three acres of land (Figure II-1). Multiple production wells would be drilled directionally from the same pad. The pad would also include a 750,000 gallon, ten to twelve foot deep disposal sump.

Figure II-2 illustrates the basic elements of a rotary drilling rig, typical of the type that would be used in developing the GRS. The rig is capable of drilling to depths of 13,000 feet. Transportation of the drilling rig, auxiliary equipment and supplies into the project area would require three-axle trailers with tandem tractors able to haul loads up to 40,000 lbs. Transfer of all equipment and supplies to a drill site would be expected to take three days.

If subsurface geology permits, air drilling would be conducted from the surface to total depth. Air drilling is generally successful in hard rock, where there is no influx of formation waters. When air drilling is not possible, mud drilling would be conducted. The typical rig used for this method would include three steel mud tanks (750 bbl. capacity

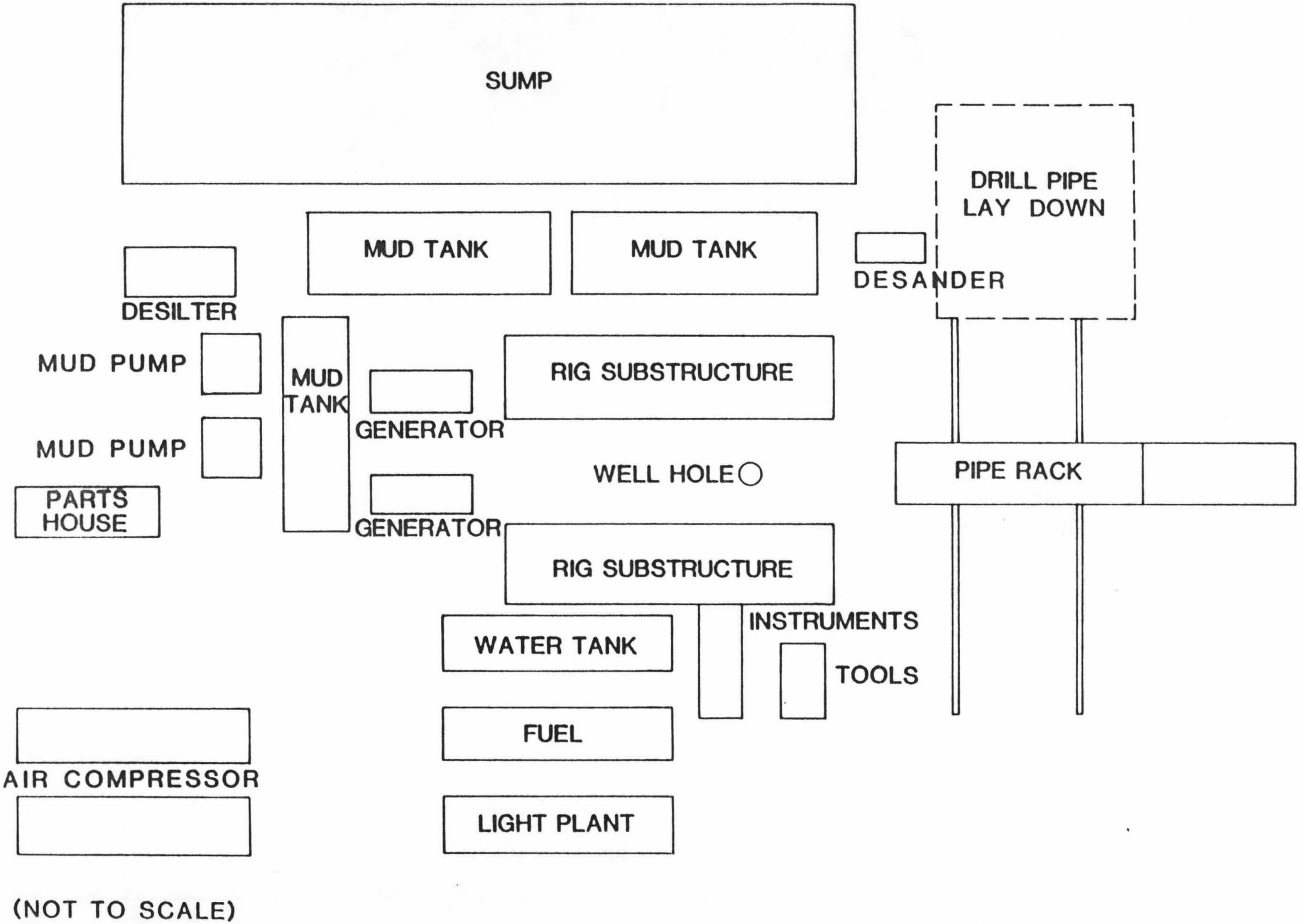


Figure II-1
DRILLING SITE LAYOUT

SOURCE: (TOWILL) 1982a.

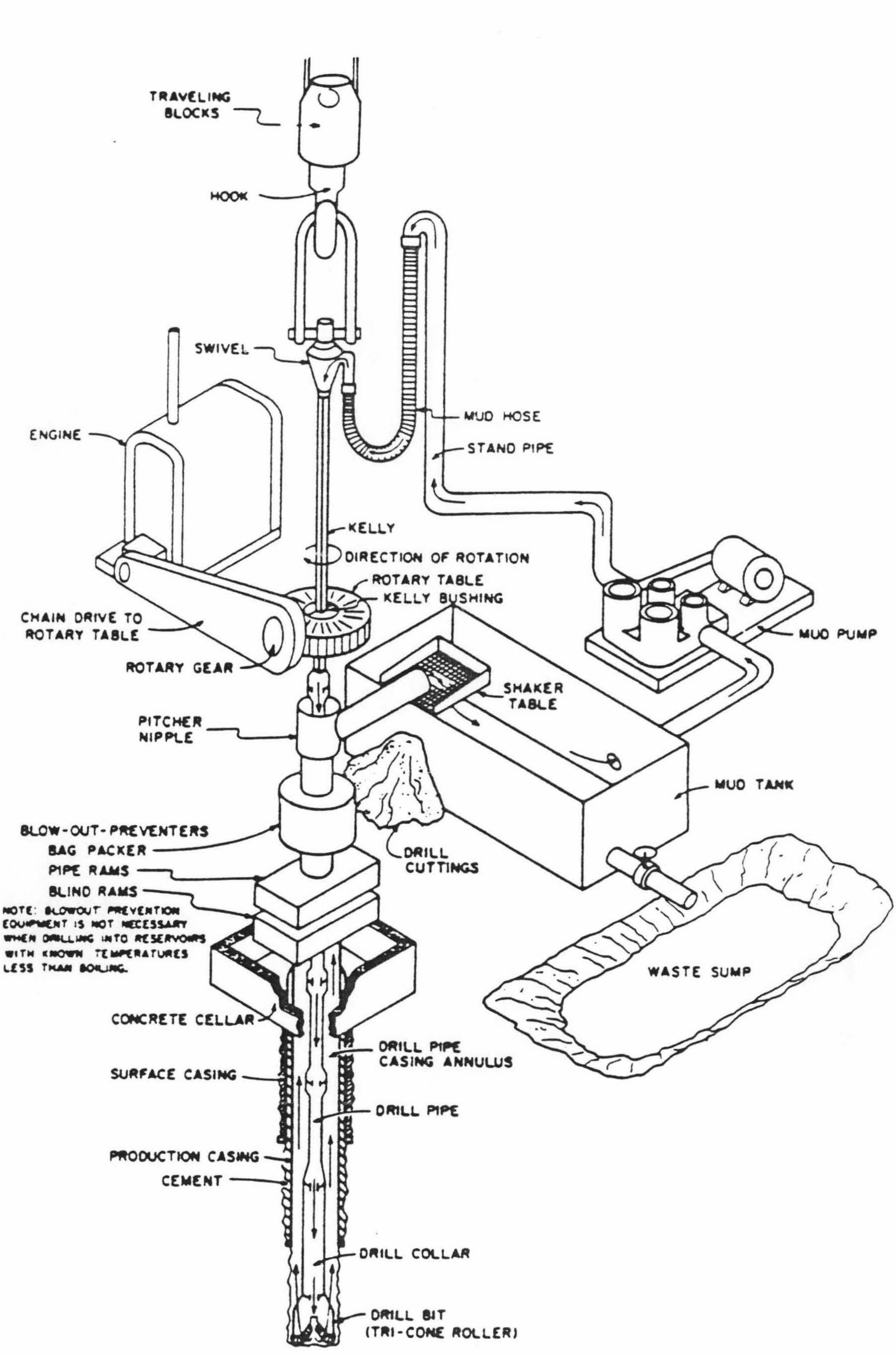


Figure II-2

BASIC ELEMENTS OF A ROTARY DRILLING RIG

SOURCE: (TOWILL) 1982a.

each); a lined earthen reserve or storage pit would be provided to handle excess fluid. This method would require on-site water availability of 2,000 barrels per day when drilling in the softest formations and approximately 100 barrels per day when drilling in hard formations.

All geothermal wells (Figure II-3) would be cased with standard drill pipe to protect the environment, groundwater resources, geothermal resources, life, health and property. Each well would have a casing head installed on the surface casing; a master gate valve would be installed to this and would be left on the well. In addition, a hydraulically operated master gate valve with annular preventer would be installed; when air drilling is being conducted, a rotating head would be installed for positive control.

All casings would be joined and cemented to assure the integrity of the well bore from surface to the producing interval. The objectives of cementing the casing are twofold: (1) to completely in-fill the cased and open hole annuli in order to resist landslides and groundwater movement; and, (2) to anchor the casing sections to each other and to the ground. The cement sheath is intended to protect the casing against possible corrosion by thermal brines and gases; prevent uncontrolled flow of thermal water and steam outside the casing; and minimize creep due to thermal expansion.

Standard safety devices would be installed to protect against a blowout from the well. The blowout prevention system would be individually designed for each cemented casing string. Safety would be stressed in all aspects of the operation. (Figure II-4 shows a typical blowout preventer system designed for high pressure wells).

When, and if, a well needs to be abandoned it would be plugged in accordance with industry standards. After the downhole plugging is completed, a cement plug would be placed in the top of the surface casing.

2.0 Well Testing and Reservoir Evaluation

The following criteria would be used to determine the potential of a reservoir to support a power generation operation at full capacity for 25-30 years: (1) depth and subsurface structure; (2) temperature of the fluid; (3) downhole enthalpy; (4) flow rate of each well; (5) chemistry of the geothermal fluid; (6) reservoir and production zone dimensions (reserves); and, (7) reinjection potential.

After each well is completed, it is tested in order to obtain an approximation of its electric power production potential. If the well has commercial production potential,

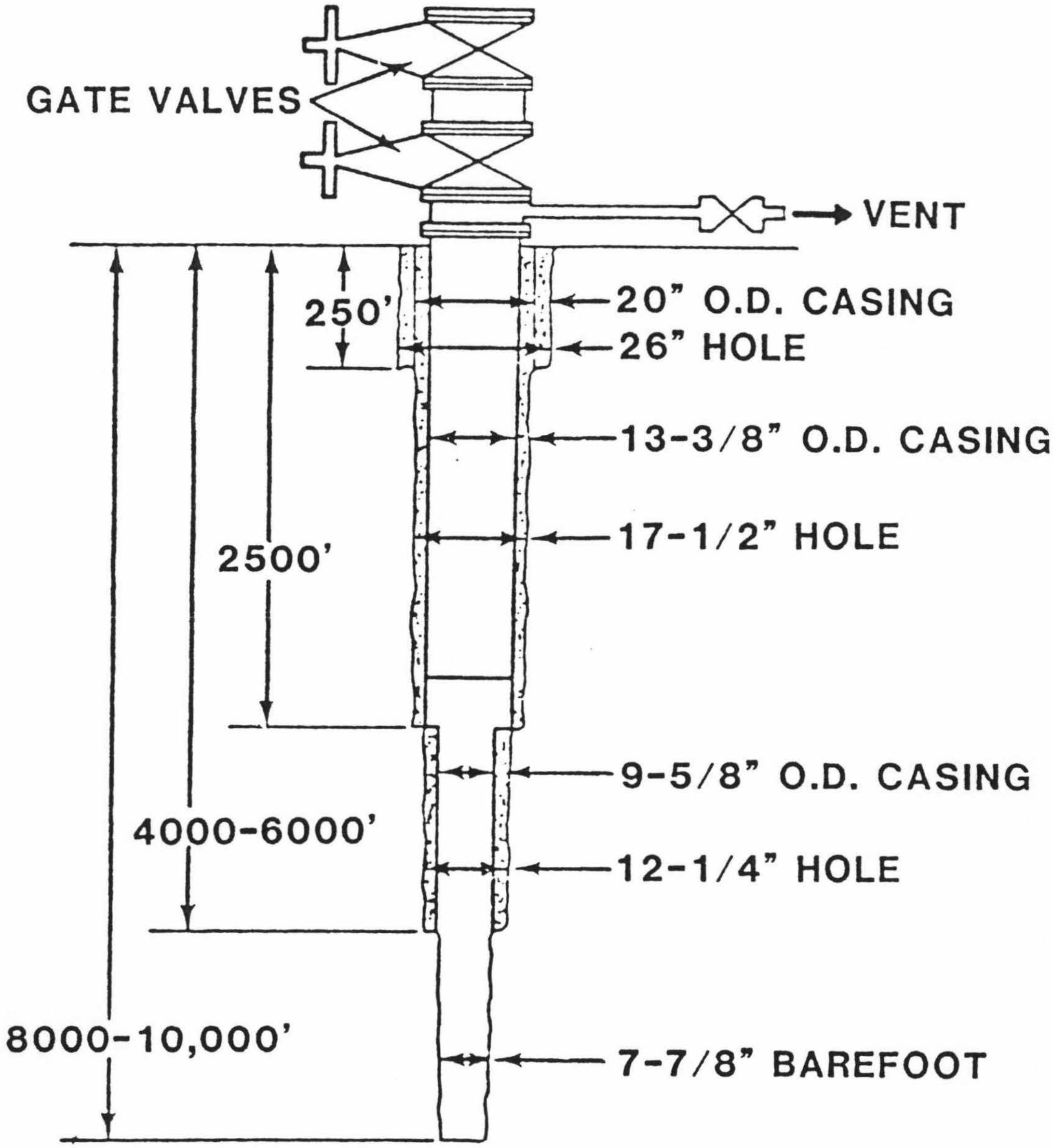


Figure II-3

TYPICAL WELL PROFILE

SOURCE: (TOWILL) 1982a.

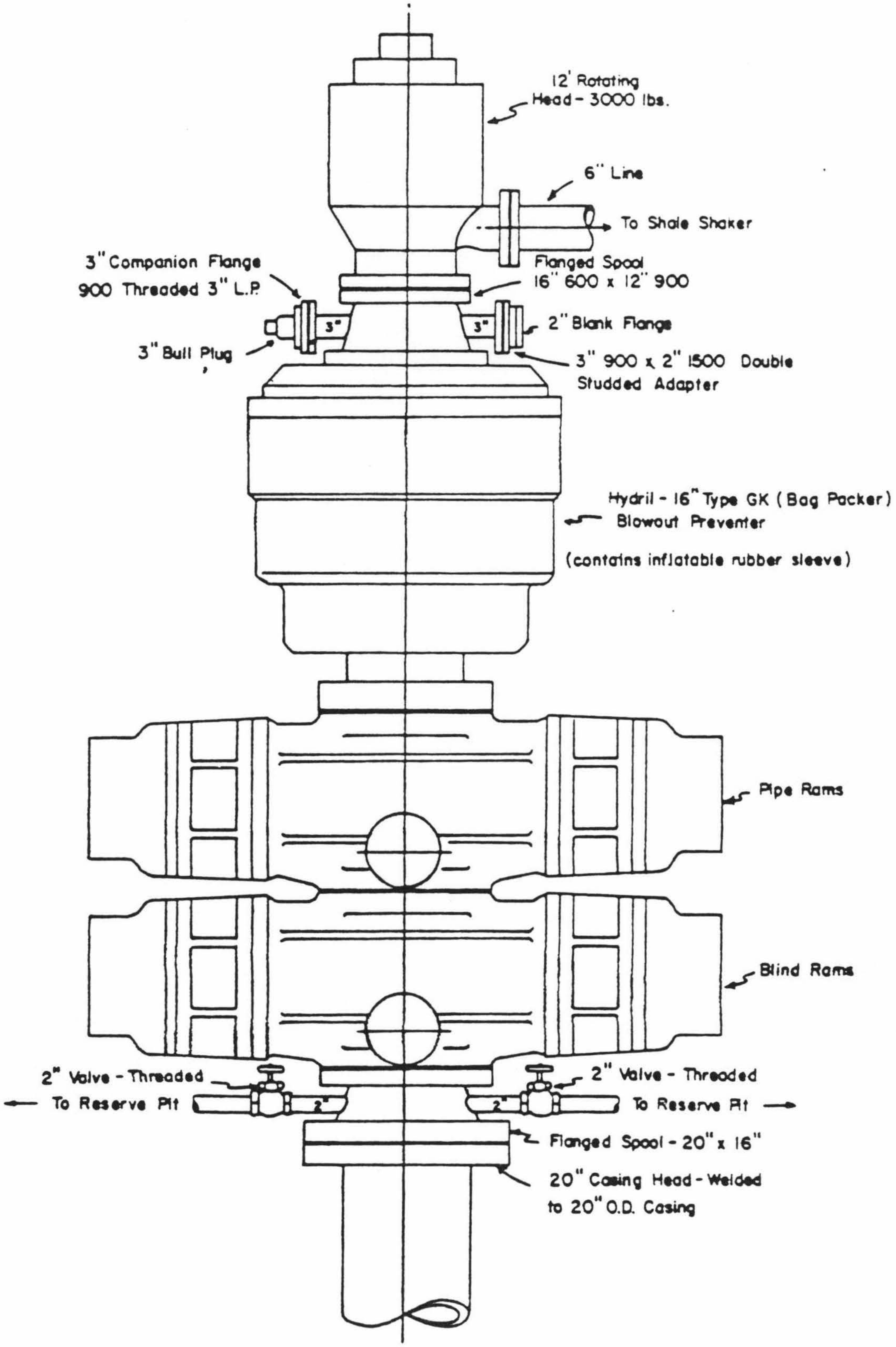


Figure II-4
BLOWOUT PREVENTER SYSTEM

SOURCE: (TOWILL) 1982a.

flow testing is undertaken to obtain complete data on the physical and chemical characteristics of the reservoir fluids. During these tests, production rates, steam water ratio, hydrogen sulfide content, salinity, fluid chemistry, and noncondensable gas content are monitored. During extended well testing, abatement systems are installed to control hydrogen sulfide (H_2S) emissions.

The data base developed from this monitoring process is necessary in order to evaluate the production capability and reliability of the resource. The data are also required to provide design criteria for the power plant and associated pollution abatement systems.

3.0 Steam Production Systems

A fully implemented steam production system would consist of production wells, well head equipment (which could include separators), pipelines and injection systems which would be managed through an integrated operations and maintenance system. Brief descriptions of major components of this system follow:

<u>Production/Injection Wells</u>: It is estimated that 15 production wells would be required for a 55 MW power plant. At 4 MW per well, this would provide sufficient capacity for 55 MW of power, with one well being a backup in case of an outage. In addition, four or five disposal (injection) wells would be required. At this stage of experience with the Kilauea east rift system, it is not possible to predict the long-term response of the wells to sustained production. Based on a study of the Cerro Prieto field in Mexico, it is assumed that a 55 MW plant would require eight replacement production wells and four replacement disposal wells over a 30 year period.

In the event of unexpected drops in power demand, load shedding would require some venting of production steam, which would have separate abatement equipment for H_2S control. The H_2S abatement of the bypass steam could be accomplished by neutralizing with caustic soda in a scrubber or such other techniques as might be available. The H_2S would then be injected in the chemically-bound condition as sodium sulfide (Na_2S) together with the effluent from the main scrubber. Part IV D of this report discusses noise effects that might be caused by a bypass flow of a portion of the resource production.

<u>Geothermal Fluid Gathering System</u>: The gathering system used to collect the hot geothermal brine would most likely consist of a pipeline network designed for two-phase flashing flow from the well sites to a flash steam

separator at the power plant. The two-phase flashing flow design would simplify the gathering process by not requiring wellhead or satellite separators, and eliminate the need for two pipelines. Considerations of topography, flow characteristics, and economy in the pipeline network would be utilized to optimize the final design of the network.

The separator (or flash tank) would be the primary component involved in the flashing process. Mixed brine and steam flow would enter the separator at the inlet from the gathering main, and that portion of the flow flashed to steam would be directed to the single stage turbine. All unflashed brine would flow to the silica drop-out pond and then to the suction header of the injection pumps. The separator would have provisions for pressure control and would be equipped with safety relief valves which would open in the event of a turbine trip or other occurrence causing the main steam stop valves to close.

<u>Geothermal Fluid Disposal System</u>: Hydrothermal fluids with chemistry similar to that expected to be found in the east rift zone are known to begin precipitating silica as they cool below 150 degrees C. Because the residence time in the flashing equipment would be less than three minutes, only a nominal amount of silica scaling would be expected at that stage. In order to eliminate potential plugging in the injection piping and wells, however, the spent fluids would be cooled in ponds to drop out silica prior to transfer to the injection pumps. The cooled fluids would be mixed with the spent caustic stream from the H_2S abatement system and the neutralizing cooling tower blowdown and pressured through polishing filters. The silica system would probably be sized to provide an hour of residence time and cooling to about 70 degrees C.

Injection pumps at the power plant would be installed to return effluent from the silica dropout system and transfer clear effluent into the ground at a suitable injection site near the geothermal reservoir. The injection pumps would receive effluent primarily from the flash separator, the cooling tower basin blowdown pumps and the bypass stream H_2S abatement system. Injection wells are required to dispose of the residual fluids of geothermal power generation in order to avoid surface environmental degradation and to restore the initial geothermal reservoir.

It is estimated that 65 to 75 percent of the original reservoir fluid would be injected. It can be assumed that a disposal well would consume more fluid than a production well can produce because of the added effect of the hydrostatic column of water. Thus, only one disposal well may be required for every three operating production wells. The following criteria for the design and operation of disposal wells are stated in approximate order of importance:

- There should not be communication between injected fluid and production wells.

- Disposal zones should be at least as deep as production zones, to allow for reheating and upwelling of the injected fluid. This would enhance the maintenance of reservoir mass and pressure, with minimum loss of temperature. Disposal depth must be set at a distance below freshwater aquifers, if they exist, to avoid possible degradation of the quality of these waters.

- Wherever possible, disposal wells should be downslope of the power plant, to allow for gravity flow disposal, at significant savings in energy.

- Wherever possible, unsuccessful wells should be used as injection sites rather than drilling additional disposal holes. This would significantly reduce drilling costs as well as reducing the environmental impacts of drilling.

- Disposal wells should be located at or as close as possible to the separator to reduce pipeline costs and the amount of disturbance to the land.

It is evident from the above criteria that disposal sites should not be selected until well testing is completed. If long-term tests show that there is no direct communication between holes in some quadrant of the field, and if permeability is adequate, unsuccessful wells in that quadrant might be converted to disposal wells. This would be the most economical disposal solution.

The injection system piping would be similar to the gathering network; the pipes would be constructed of carbon steel and mounted above ground. All piping would be nominally insulated, as required, to preclude temperature losses which could lead to: lower steam enthalpy; scale buildup in the injection system piping; and for protection of personnel.

B. DESIGN, CONSTRUCTION AND OPERATION OF GEOTHERMAL POWER PLANTS

The technical description which follows is based on available specifications for a 55 MW power plant as compiled from existing literature relating to proposed geothermal developments in the Puna area [e.g. Revised Environmental Impact Statement for the Kahauale'a Geothermal Project (Towill, 1982a) and Final Supplemental Environmental Impact Statement to the Revised Environmental Impact Statement for the Kahauale'a Geothermal Project (True/Mid-Pacific, 1986)]. Descriptions of typical 12.5 MW and 25 MW plants are included in Appendix B.

Drawings of typical operating units are included in this section. These drawings depict plants that have been designed and are in operation at other locations. The power plants that would be constructed for a 500 MW system would be expected to be similar to those described. The actual design would be based on the nature and characteristics of the resource discovered; the most appropriate abatement system available at the time of construction would be utilized.

The power plants described here have been widely used where the geothermal resource has high temperature, the condition existing in Hawaii. Another power plant concept which has recently become prevalent for lower temperature regimes is the binary (closed-cycle) concept. The binary concept is not as thermally efficient as the standard turbine concept described herein, so it is not likely to be the first preference. Because it is a "closed" system, the binary concept is generally considered by the industry to be somewhat more environmentally benign than the plant described herein.

1.0 Building and Site Characteristics

A 55 MW geothermal plant is shown in perspective in Figure II-5. This scale of operation requires a hydrogen sulfide abatement facility and silica drop-out system. The overall site acreage requirement is approximately 8 acres, including a 60-foot cleared area around the site for security and safety purposes. Figure II-6 illustrates a conceptual site plan and a typical section of a 55 MW plant. The overall dimensions of the plant would be approximately 170 feet by 80 feet by 75 feet high.

2.0 Gathering and Injection System

Figure II-7 illustrates the gathering and injection system for a 55 MW power plant. It diagrams the flow of the geothermal fluids from the well field into the power plant. The hot mixed

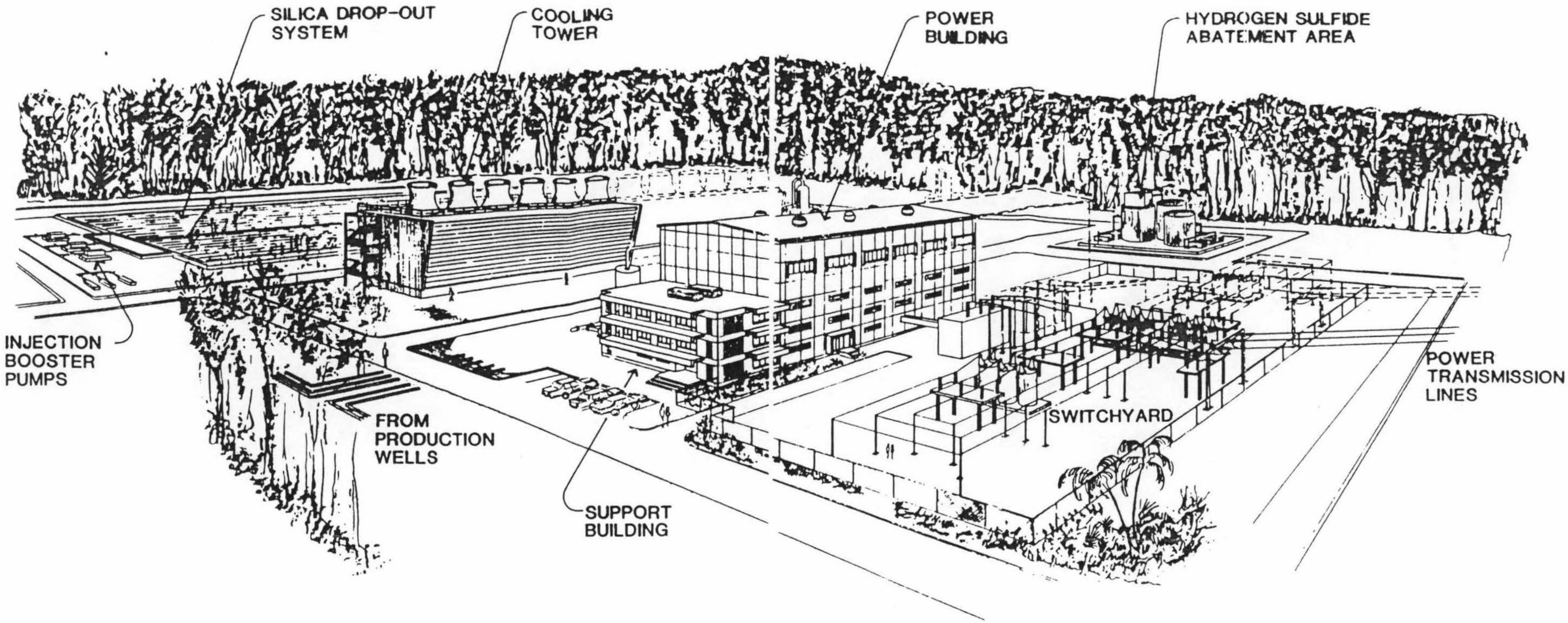


Figure II-5
55 MWe POWER PLANT: PERSPECTIVE

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

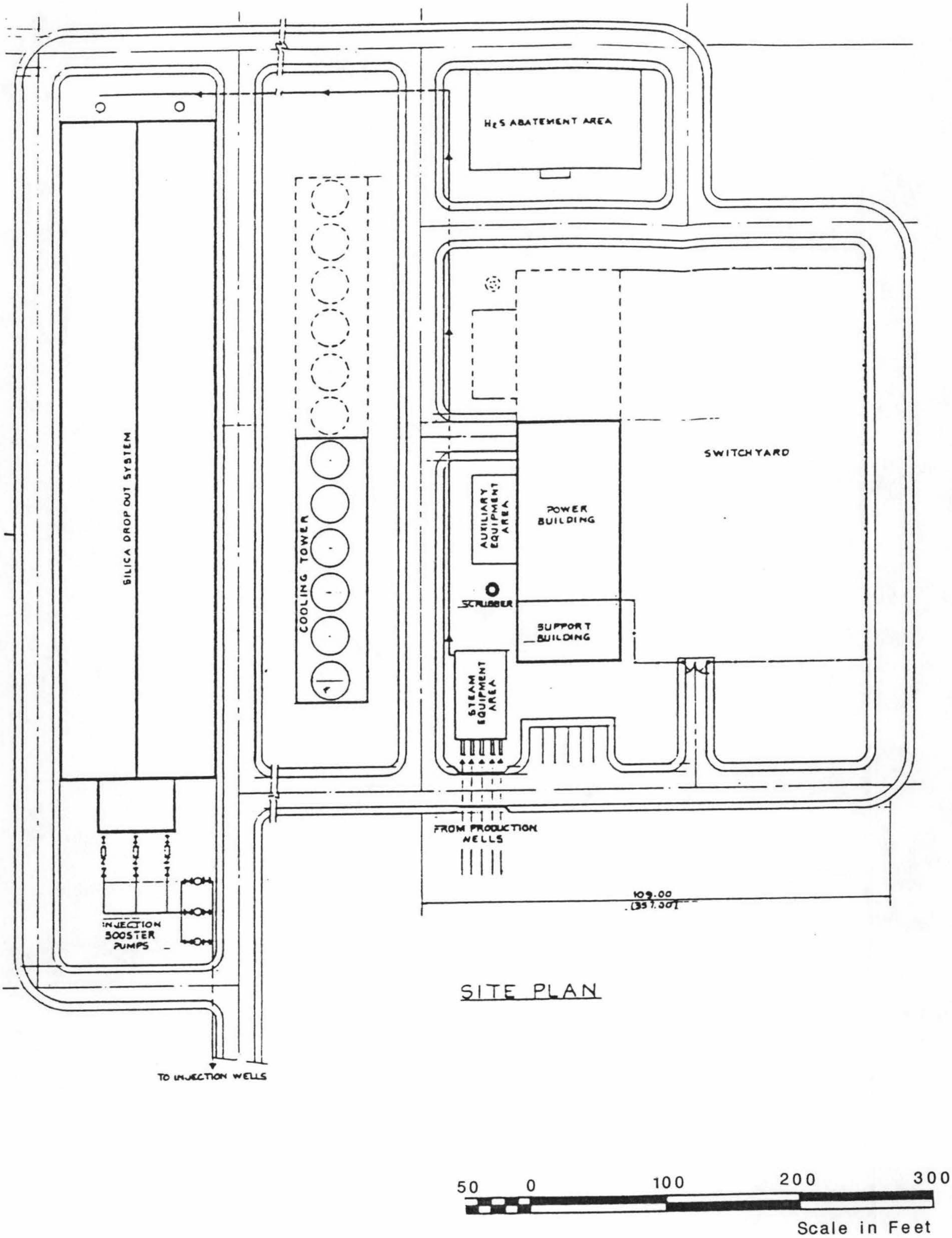


Figure II-6

55 MWe POWER PLANT: SITE PLAN

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

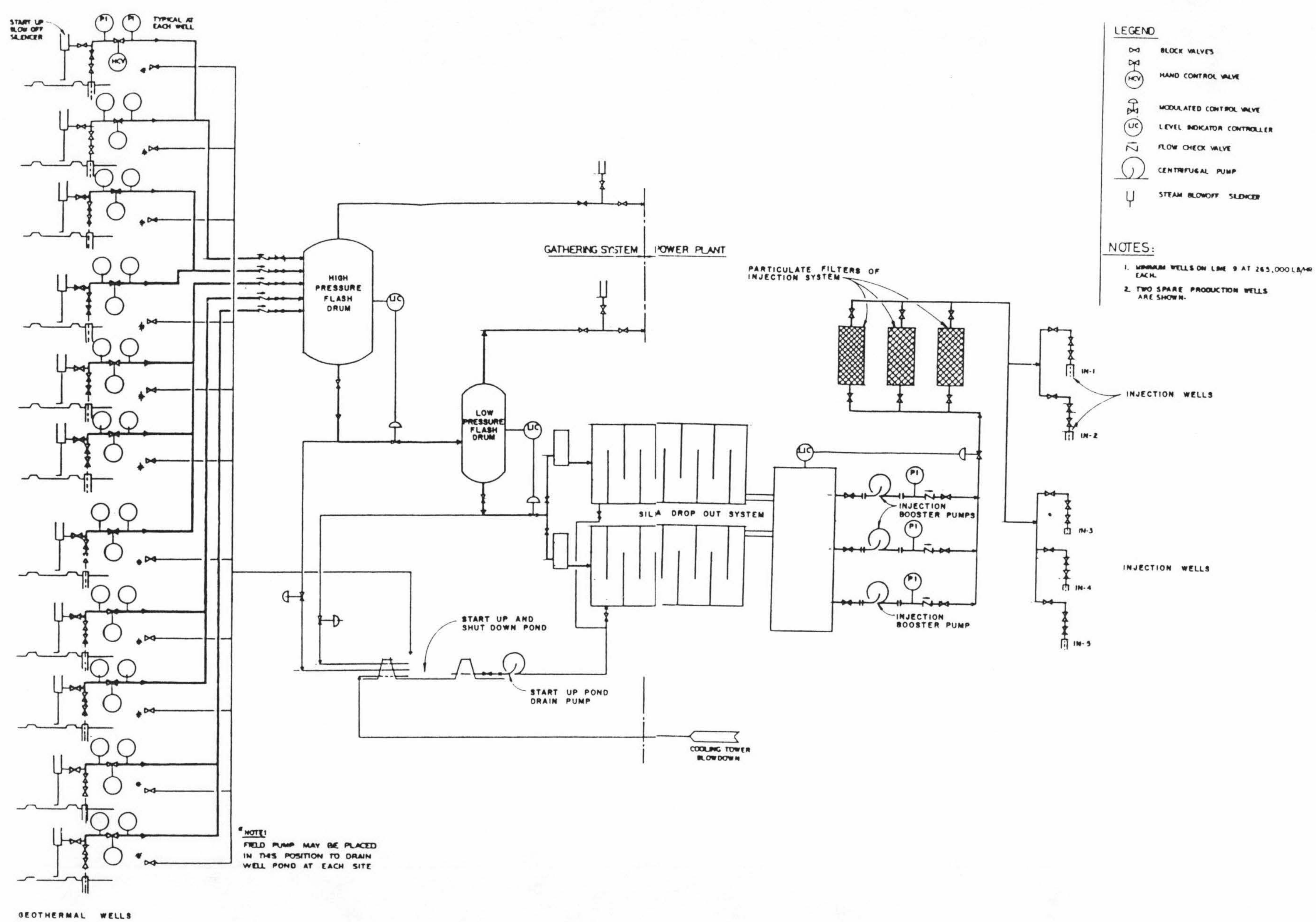


Figure II-7

55 MWe POWER PLANT: GATHERING AND INJECTION SYSTEM

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

brine and steam flow first enter a high pressure flash drum, followed by entry into a low pressure flash drum. The portions flashed to steam are directed to the double pressure, double flow steam turbine. The unflashed brine is directed to the flash steam mufflers, the silica drop-out system and the injection well pumps.

3.0 Turbine-Generator System

The steam turbine for a 55 MW plant would typically be a double pressure, double flow, impulse/reaction type condensing unit with single cylinder, direct-coupled to a totally enclosed hydrogen-cooled generator. The turbine generator would be a double pressure admission condensing unit. The equipment would include automatic tripping devices required to protect the unit when a malfunction occurs.

Concrete pedestals on rigid mat foundations would support the turbine generators and main condenser units of the plant. The turbine generator pedestals would extend approximately 25 feet below ground level to allow space for the main condenser. The "hot wells" for the main condensate pumps would extend further to about 33 feet below ground. The liquid level in the condenser would be controlled by automatic liquid level controller. All the condensate from the geothermal steam would be returned to the cooling tower. Makeup water for the cooling water system would be provided from the steam condensate.

4.0 Energy Conversion (Process Systems)

Steam from the gathering systems would be supplied to the plant steam lines at the plant boundary (Figure II-8). A steam line pressure relief system would be installed for emergency shutdown of the turbine generator. Steam would be piped to the turbine, and in smaller quantities, to the turbine gland seals, first stage noncondensable gas ejector and second stage noncondensable gas ejector. Turbine steam would be exhausted downward to the shell side of a surface condenser. Cooling water would flow through the horizontal condenser tubes in a multi-pass arrangement.

Two full capacity transfer pumps (one spare) would pump the condensate from the main condenser hot well to the cooling tower basin. Condensate from the inter-condenser would flow by vacuum pressure differential to the main condenser. Two 60 percent capacity main circulating water pumps would pump cooling water from the cooling tower forebay through the main condenser, inter-condenser, generator heat exchanger, lubricating oil cooler, air compressor cooling system, and back to the sprays in the cooling tower. These main circulating water pumps operate when the turbine generator is operating. An auxiliary cooling water pump would supply cooling water to essential heat

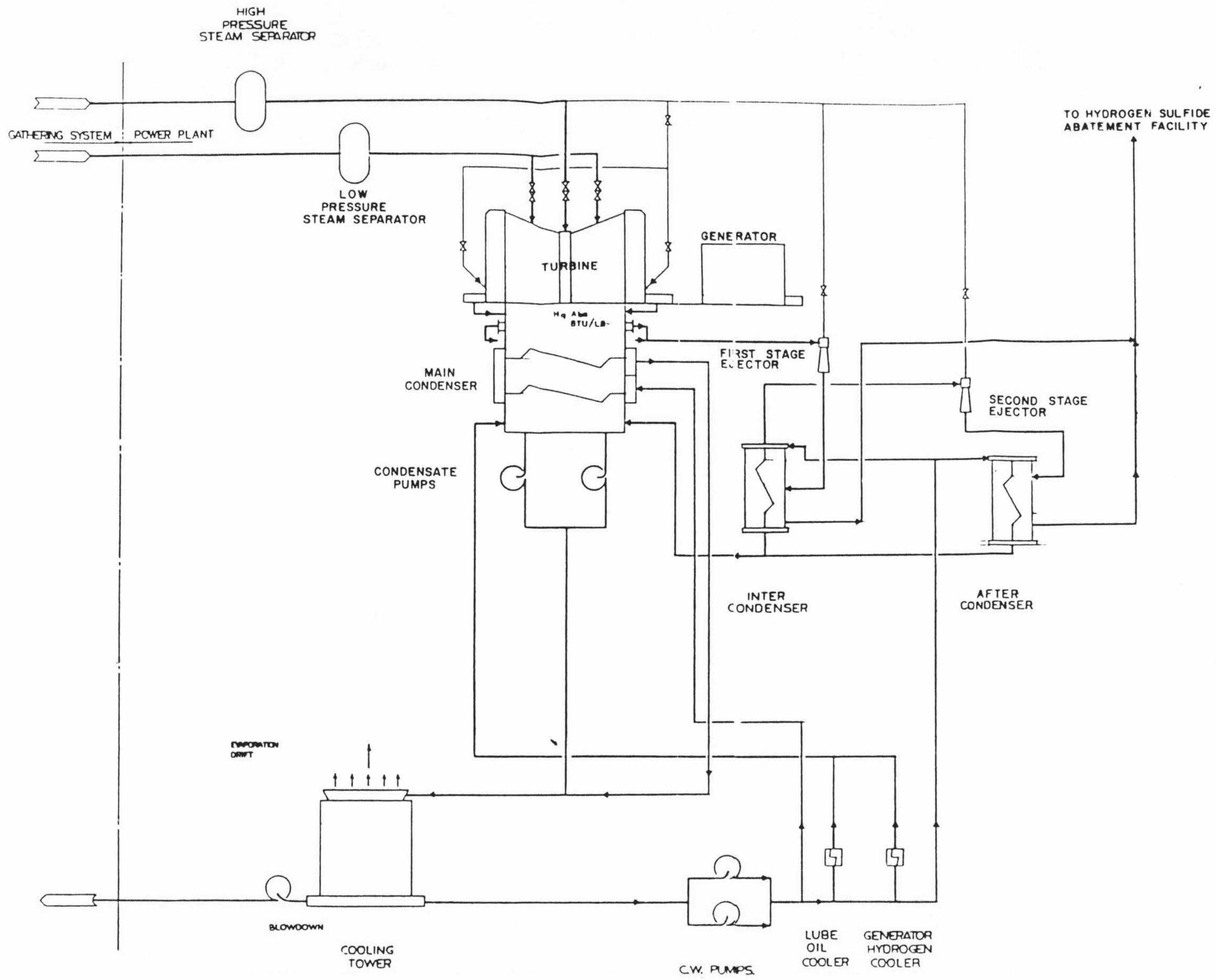


Figure II–8

55 MWe POWER PLANT: FLOW DIAGRAM

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

exchangers when the turbine generator is shutdown. Cooling tower blowdown would be required and would be based on concentrations of treated makeup water. The blowdown would be pumped into the brine disposal system.

Discharge from the first stage (main condenser) steam jet ejector would enter an inter-condenser where noncondensable gases would be drawn off by a second steam jet ejector discharging to the after-condenser. Surface type condensation equipment would be used in order to permit extraction of the noncondensable gases for environmental cleanup by chemical or incinerator process.

5.0 Electrical System

Electrical power would be transmitted to the transmission line through a main step-up transformer. The transformer would be connected to the line through a group operated disconnect switch which would be equipped with a high speed grounding switch. The grounding switch would be operated only in the event of transformer malfunction. Transmission line faults would be cleared by a circuit breaker.

The station bus would be connected by an air circuit breaker to the generator and the low voltage side of the main step-up transformer. This bus would also supply power to the auxiliary transformer and to the steam gathering and injection pump system through fused load break switches.

6.0 Typical Power Plant Construction Activities

Construction at any given plant site would be preceded by extensive design, planning and ground surveys. The proposed site would be staked and surveyed by engineers, archaeologists, ecologists and geophysicists. Site location adjustments would then be made as required. Of particular concern would be the presence of geophysical faults and cracks that could make a planned site dangerous. In general, plant sites would be located on higher ground, if practicable, to minimize volcanic hazards.

Site preparation would begin with vegetation clearing and grubbing. Care would be taken to preserve larger trees if possible and include them in the site landscaping. Site grading requirements would be minimized to the extent possible by adjusting site structures to the existing elevations. The pahoehoe lava provides an excellent structural foundation, given the absence of lava tubes. The foundation investigations would place particular emphasis upon the definition and avoidance of lava tubes, if any are identified on the sites. The prevailing gentle slope of approximately 3 percent would permit structure construction without excessive excavation and embankment.

7.0 Power Plant Operations/Abatement Systems

Prior to the construction and/or operation of power plants, Authority to Construct (ATC) and Permit to Operate permits would be obtained from the State Department of Health. The ATC permit application would specify the equipment and procedures that would be used to maintain air quality and assure that the power plant would meet all applicable environmental protection regulations.

Abatement systems would be installed to control hydrogen sulfide (H_2S) emissions during power plant operations. H_2S is a constituent of the geothermal fluid (in varying degrees) as a noncondensable gas. There are several systems available for hydrogen sulfide abatement. The method incorporated in each plant would be the choice of the developer subject to application of BACT. Summaries of seven of the alternative control technologies which follow are based on data presented in Fluor Technology (1987); information about the eighth alternative control system, Dow Chemical's RT-2 System, was provided by staff of the DBED Energy Division:

<u>Burner/Scrubber System</u>. Noncondensable gases from the condenser are removed and sent to the combustor and are incinerated at 2000°F (1367°K) with excess air to convert the H_2S to SO_2. The hot gas is quenched by direct contact with water and cooled to approximately 180°F (355°K). The gas is then contacted with an aqueous sodium hydroxide solution in a scrubber. The resulting noncondensable vapor phase H_2S control efficiency is 99.98 percent while 0.21 percent of the pre-control H_2S is converted to SO_2.

<u>Stretford Process</u>. A Stretford unit converts H_2S to elemental sulfur. H_2S is essentially oxidized by air to sulfur and water with vanadium as a catalyst. The Stretford process can achieve a noncondensable vapor phase H_2S emission control efficiency of 99.91 percent. This process has a significant drawback in that the vanadium is a toxic substance.

<u>LO-CAT Process</u>. The LO-CAT Hydrogen Sulfide Oxidation Process is licensed by ARI Technologies, Inc. Noncondensable gases are removed from the condenser and sent to the LO-CAT unit where the gas is bubbled into the bottom of the absorber chambers in the LO-CAT absorber/oxidizer. As the gas bubbles up through the slightly alkaline solution, the H_2S is absorbed, ionized, and finally oxidized to sulfur by the ferric (Fe^{+++}) ions. The LO-CAT process can achieve a noncondensable vapor phase H_2S emission control efficiency of 99.96 percent. While the process has been used to abate gases from other

industrial processes it has not been demonstrated at a geothermal power plant.

Claus-SCOT Process. The Claus-SCOT process consists of two processes in series. The SCOT (i.e., Shell Claus Offgas Treating) removes sulfur from the gas stream unit exiting the Claus unit. The Claus process unit is available from a number of companies, but the SCOT unit is licensed by Shell Oil Company.

Noncondensable gases from the steam condenser are fed to the Claus unit where a furnace burns approximately one-third of the H_2S to SO_2. The remaining H_2S reacts with the SO_2 to form elemental sulfur and water. The gas leaving the furnace is cooled to condense any sulfur that has formed, while the heat removed from the gas stream is used to generate steam that is added to the geothermal steam. The cooled gas flows through a series of reheaters and catalytic reactors where the gas is first heated to reaction temperature then cooled to condense the sulfur. The Claus unit tail gas is then treated in the SCOT unit and then to a catalytic incinerator prior to venting to the atmosphere. The Claus-SCOT process achieves a noncondensable vapor phase H_2S emission control efficiency of 100 percent, although 0.54 percent of the pre-control H_2S is emitted to the atmosphere as SO_2.

Selectox/CI Process. The Selectox/CI process is similar to the Claus process but differs in the first stage combustion process. The Claus process burns a portion of the H_2S with air to form SO_2 which is then reacted with the remaining H_2S to form elemental sulfur. The Selectox process accomplishes the same combustion catalytically which allows a lower temperature to be used. The Selectox/CI process achieves an H_2S emission control efficiency of 100 percent, although 0.2 percent of the pre-control H_2S is emitted to the atmosphere as SO_2.

Clinsulf Process. The Clinsulf process is an adaptation of the Claus process. The principal of the Clinsulf process is to operate reactors both above and below the sulfur dew point temperature. Operation below the dew point causes the sulfur to adsorb onto the surface of the catalyst. The adsorption removes elemental sulfur from the reaction causing more sulfur to be formed. The catalyst is then heated to remove the sulfur product. The Clinsulf process emits only trace amounts of H_2S (plus 0.59 g/sec from the condensable gas stream), although 0.81 percent of the pre-control H_2S is emitted to the atmosphere as SO_2.

Reinjection. The noncondensable gases are removed from the condenser, compressed to approximately 200 pounds per square inch gauge (psig) and sent to an absorber. The absorber contacts the noncondensable gases with the cooling tower blowdown water. The H_2S and CO_2 in the noncondensable gas stream dissolve in the water while the other components (nitrogen and hydrogen) do not dissolve. The gaseous components which do not dissolve in the water pass through the absorber and are vented. The water containing the H_2S and CO_2 is pumped from the absorber into an injection well for disposal.

Reinjection results in only trace emissions of H_2S, with a noncondensable vapor phase control efficiency 99.96 percent.

Dow Chemical RT-2 Process. The RT-2 system is a proprietary abatement process based on incineration and scrubbing. It is in use at the 3 MW HGP-A plant in Puna, as well as at the Geysers geothermal development in Northern California.

Other effluents of operation include: (1) process fluids; (2) cooling tower blowdown and excess geothermal fluid, which are sent to the injection station; and, (3) geothermal fluid in the form of water vapor and drift droplets, released to the atmosphere from cooling tower exit air.

The vapor and drift released to the atmosphere from the cooling tower would contain small concentrations of dissolved solids and noncondensable gases which are present in the geothermal steam. Although the gases would be present in the same amount, the drift would contain liquid with a dissolved solids concentration similar to the cooling water blowdown. The drift loss would be small and should percolate into the lava.

A lower percentage of the hydrogen sulfide in the fluid that circulates through the cooling tower would be removed by prior treatment, resulting in a very low rate release of hydrogen sulfide to the atmosphere at or below the required standards for emission.

8.0 Power Plant Maintenance

In general, geothermal power plants are designed for long-term, base load operations with minimal operation and maintenance costs. Maintenance would require a total of five weeks per year of which four weeks would be required for the annual scheduled turbine and plant overhaul.

C. POWER TRANSMISSION WITHIN THE GRS

1.0 Description

Electric power at the plants would be generated at 13.8 KV and transmitted to the power transmission lines through main step-up transformers converting the voltage to 138 KV at the plant site.

If a redundant transmission line is installed a physical separation between the two power transmission lines, as shown in Figure II-9, would be required. An overall corridor width of 50 feet would be needed for a single 138 KV transmission line; the second 138 KV line would be constructed 60 feet away from the first line to avoid interference if one line is damaged and falls toward the other.

Wooden power poles would probably be used along most of the transmission line. These poles would typically reach a height of 90 feet above ground; an additional 10 feet would extend below ground (Figure II-9). The average span length between the poles would be 600 feet. Special steel pole structures may be required at angles and deadends, for long spans, and where special visual and/or safety considerations exist.

Because of the natural sag (catenary) of the conductors, 90 foot high poles would provide a minimum clearance of 30 feet between the ground surface and the conductors. Each of the 138 KV lines would have one aluminum conductor for each of the three phases. Each phase (conductor) would be suspended from the pole structure by a single 8-bell insulator string, with vertical spacing between phases of 12 feet. The conductors would be protected from lightning strikes by an overhead shield wire mounted on the tops of the wooden poles and connected by ground wires to ground rods driven into the earth at the bottom of the poles.

2.0 Construction

Planning, design and construction of the power lines would proceed with the decision to construct the initial power plant. The initial planning and ground surveys for service roads would include the right-of-way width to accommodate the power lines.

Ideally, the power line corridors would be located along side the right-of-way of the service roads connecting the power plants and well pads, however, there is a need to minimize the total number of AC power transmission lines within a GRS.

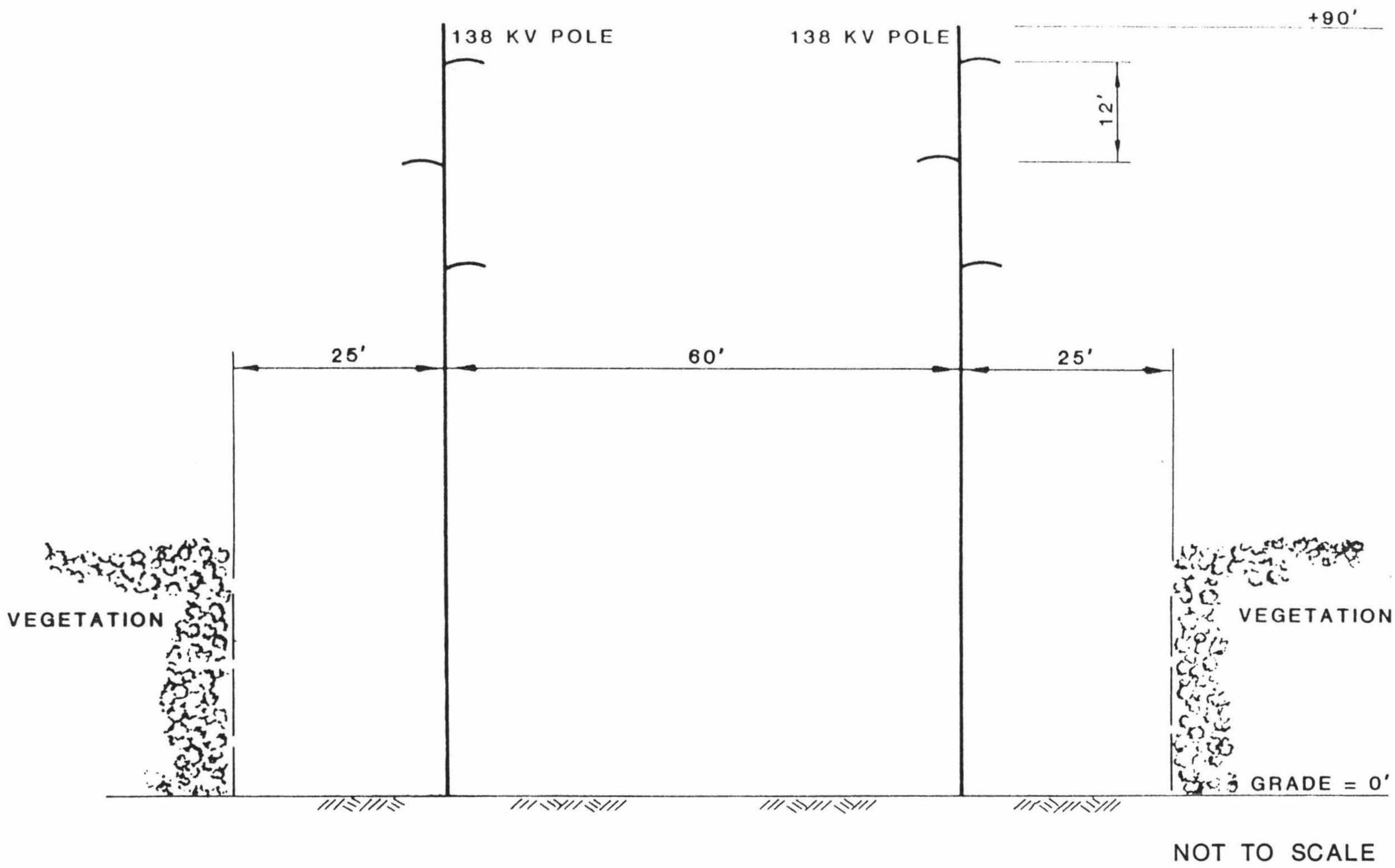


Figure II-9

138 KV TRANSMISSION LINE CORRIDOR

SOURCE: HECO

Construction of transmission lines would occur after the service roads within each zone are developed; probably at the same time as power plant construction. Construction activities would consist of clearing and site preparation for the right-of-way and pole sites; erection of transmission pole and line stringing; and clean-up and reclamation.

Site Preparation and Vegetation Clearing. A site would be cleared and leveled for assembly and erection of each transmission pole. Conductor stringing sites would also be leveled and cleared at approximately 3.1-mile intervals along the right-of-way. These stringing sites would be used to pull conductors into place and for tensioning the conductors. In addition, trees that might contact the lines during wind-induced swing, even if located outside of the corridor, would also be removed or topped.

Line Construction. A wagon drill mounted on a truck or tractor would be used to dig holes for the poles. The poles would then be erected by crane. The holes would be backfilled after the poles are erected. Various pieces of heavy construction equipment would be used in the transport, assembly and erection of the poles. Blasting may be required to excavate the pole holes in areas of hard rock.

The transmission line conductors would be attached to the structures by a "tension-stringing" method whereby a bulldozer or helicopter would be used to pull the sock line (a lightweight leader cable) down the center of the right-of-way. The sock line would then be used to pull the conductors into place under tension, using a vehicle operating along the access road and power line centerline.

Cleanup and Reclamation. Vegetation cleared during line construction would be left on site, except for any large trees which may be harvested. Disturbed areas would be restored where necessary. All areas disturbed during line construction would be permitted to revegetate with appropriate natural species already present in the area.

3.0 Operation and Maintenance

The developer's transmission line responsibilities would include operation and maintenance of the lines. The transmission line corridors would be inspected at least twice a year for possible problems with the power poles and electrical systems. Vegetation would be periodically trimmed, as needed, to maintain the desired right-of-way and clearance to the poles and conductors.

4.0 Converter Station

The location of the Alternating Current/Direct Current (AC/DC) power converter station in the central portion of the Kamaili GRS, as shown on (Figure I-5), is conceptual. Its ultimate location is dependent on the location of the geothermal power plants. Evaluation of potential interisland cable power line corridor alignments is not within the scope of this environmental review.

D. ACCESS AND SERVICE ROADS

1.0 Planning and Design

At present there is a limited road network within the three GRS of the east rift zone. The conceptual geothermal system indicates an ultimate road network to support the planned 500 MW production level. As illustrated, there would be access roads leading from existing roads into the GRS and service roads connecting the separated power plant sites.

Constraints in road design in the east rift zone include the need to: (a) avoid volcanic hazards (geophysical faults and cracks) that characterize the rift zone; (b) avoid areas identified to include endangered species; (c) avoid residential communities; and, (d) minimize the high cost of construction. In most cases, well field roads would traverse the rift zone at a right angle to minimize the obstacles in crossing the faults and cracks of the rift zone, and to provide the most direct routes away from the rift zone in case of volcanic activity. In addition, the service road corridors would need to be essentially straight, in order to accommodate power transmission lines. An evolutionary approach for the service roads would be required for construction, that is, an initial minimal one-lane, unpaved road could evolve into a two-lane paved road with provision for power transmission line corridors.

Figure II-10 shows conceptual road designs for service roads. The main service roads are the roads which interconnect the power plants. The well field roads are service roads leading from the power plants to the well pads.

Development of the roads would initially be limited to the access and secondary roads required to move the drilling equipment to the first drilling site. Other alignments would be selected as the development progresses. The initial roads would be designed for low speed movement of trucks and trailers to the drilling sites. An estimated 40 to 50 trailer loads would be used to move the disassembled drilling rig and equipment by truck tractors to the drilling site.

Fully developed service roads would consist of two-lane roadways (24-foot width) with three-foot shoulders and corridor provisions on each side for 138 KV power lines. Well field roads would also include 10-foot geothermal pipeline corridors with pipelines to carry the hot geothermal fluids from the well sites to the power plants and the spent fluids from the plants to the injection well sites. These steel pipelines would be designed to blend in with the natural background colors and would be elevated on saddles 4 to 6 feet above ground.

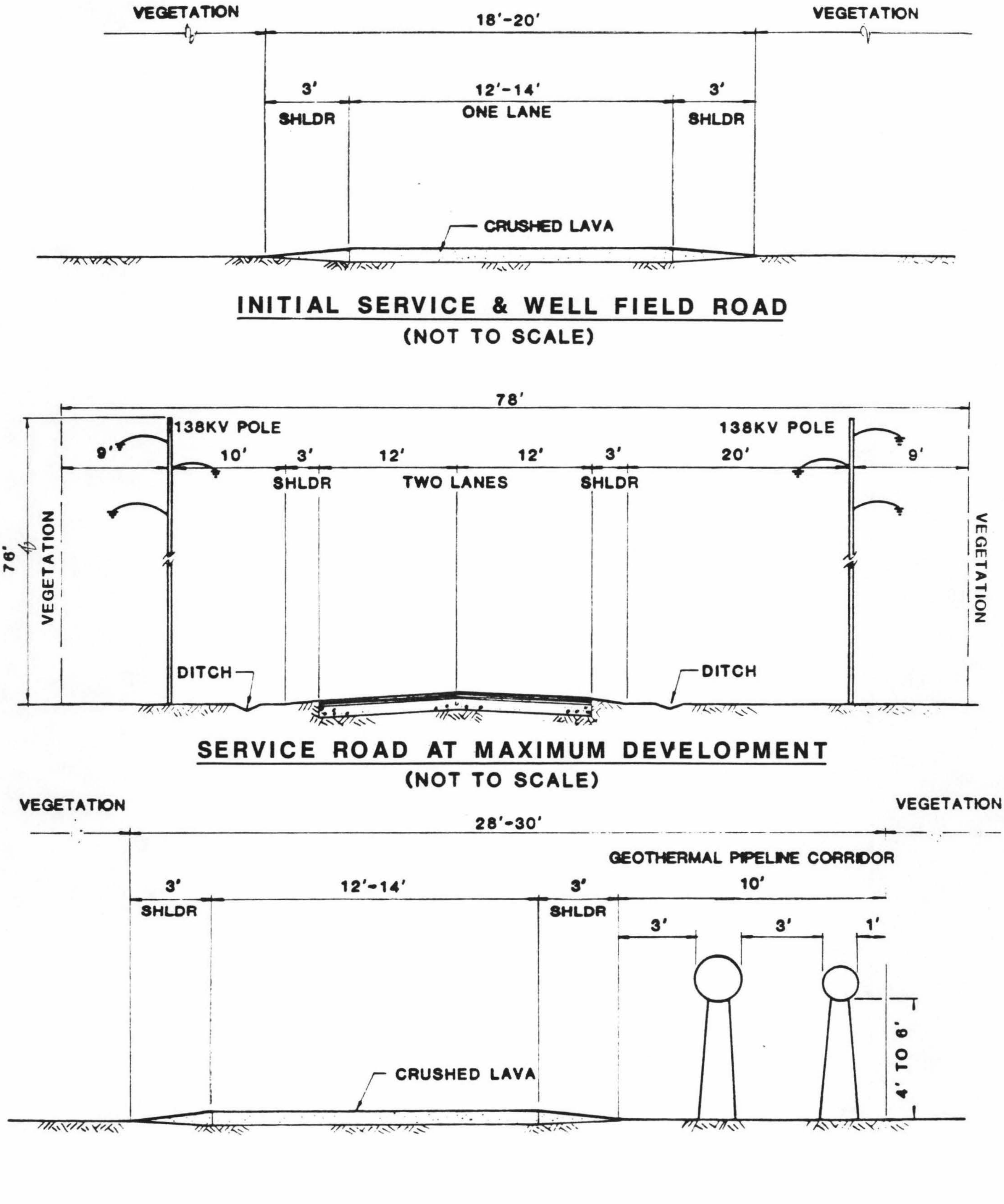


Figure II-10

ROAD CROSS-SECTION

SOURCE: (TOWILL) 1982a.

2.0 Road Construction

Construction of initial service and well field roads would follow existing practices on the Big Island for construction of access roads through forested areas. After field surveys and, where required, consultation with a qualified botanist, vegetation would be cleared to a width of 18 to 20 feet, which would include shoulders and some width for turnouts and passing. A large bulldozer would proceed down the alignment, dozing away the vegetation to the desired clearance width. Larger trees that can not be avoided would be cut and removed to the side of the cleared area for later harvesting, if desired. Steel rollers would be used for crushing the lava; a motor grader would shape it to the desired grade and cross section for truck traffic. If required, Aa lava fill material would be trucked in and used to build up the road bed. A 14-foot roadway width would be maintained, except where construction obstacles (e.g., large trees) indicate a reduced 12-foot width.

3.0 Road Operation and Maintenance

Road operation and maintenance activities would be the responsibility of geothermal developers and/or power plant operators. Access would be controlled in the vicinity of power plant sites and well fields; that is, only project and government agency personnel would be permitted to enter the area. In general, public access would be restricted in an area of active drilling or power generation operations, due to safety and security considerations.

PART III: ECONOMIC ANALYSIS

A. ASSUMPTIONS

The development schedule, cost and employment estimates in this analysis are based on the "Undersea Cable to Transmit Geothermal-Generated Electrical Energy from the Island of Hawaii to Oahu: Economic Feasibility," (DAHI, 1988). Appropriate adjustments were made to the quantities given in the DAHI report to reflect the fact that larger but fewer power plants are assumed. The technical assumptions (e.g. numbers of wells, costs and employment) in the following analysis are based primarily on the expectations of Puna Geothermal Venture, Inc. as of late 1987 and early 1988 and should be considered conceptual. The technical assumptions of other developers and actual experience in the field may be different. Additional information on employment estimates was obtained from Pacific Gas and Electric Company, based on their geothermal operations at the Geysers north of San Francisco.

The following economic analysis differs from the conceptual development illustrated in Figure I-5 in number of projected plants. Please refer to Part I, Section E-2, Basic Assumptions, for a discussion of the rationale for this difference.

The schedule for completion of operational geothermal plants, which is consistent with that given in the DAHI report, is:

Month	Year	Unit	Cumulative Capacity (MW delivered)
Jan	1995	1	50
Mar	1996	2	100
May	1997	3	150
Aug	1998	4	200
Oct	1999	5	250
Jan	2001	6	300
Mar	2002	7	350
May	2003	8	400
Aug	2004	9	450
Oct	2005	10	500

Development would begin about three years before the first plant becomes operational. Consequently, construction would span a 14-year period.

B. ECONOMIC CHARACTERISTICS OF THE PROPOSED DEVELOPMENT

1.0 Construction Activity

<u>Development Costs (1986 dollars)</u>. It is estimated that 15 production wells would be required for each 50-MW power plant. At 4 MW per well, this would provide sufficient capacity for 55 MW of power, with one well being a backup in case of an outage. In addition, three injection wells would be required for each power plant. In order to provide these 18 usable wells, it is further estimated that an average of four unusable wells would be drilled which must be abandoned because they are unusable for production or injection of the geothermal fluids. The entire well field for 10 power plants would total about 220 wells: 150 production wells, 30 injection wells, and 40 unusable wells. The total development cost for these wells, assuming $2.5 million for each production well and $2 million for each injection and unusable wells, would be $515 million.

For the steam-gathering system the estimated cost is $10.8 million per power plant, or $108.8 million for ten plants.

The cost of a 50-MW power plant is estimated to be $52.6 million (based on DAHI's estimate for a 25-MW plant and scaled up appropriately) (DAHI, 1988); for ten plants, the cost would be $526 million.

For the complete 500-MW geothermal power generating system - including the well fields, steam gathering system, and power plants-the estimated development cost is $1,149 million. Over the 14-year construction period, the construction expenditures would average about $82.1 million per year.

<u>Construction Employment</u>. In order to drill the required number of wells, seven 12-man drilling crews, with each crew drilling about three wells per year, are expected. Total employment for drilling would be about 85 jobs. Construction employment required to build ten power plants and associated piping for the system-gathering system is estimated to average 155 jobs. Thus, total construction employment for wells, the steam-gathering system, and power plants is expected to average about 240 jobs over the 14-year construction period.

<u>Construction Wages</u>. Construction wages would total about $8 million per year over the construction period (an average of 240 jobs at $33,426 per job (DBED, 1987b).

2.0 Operations

Energy Sales. Accounting for line losses, 500 MW of "baseload" geothermal power would result in the sale of about 4.38 million kilowatt hours (kWh) of energy to Oahu, and reduce oil imports to Hawaii by over 6.6 million barrels annually. Assuming an average fuel-oil cost of about $35 per barrel as the basis for determining the value of geothermal energy, geothermal energy sales would amount to over $230 million annually. Fuel oil at $35 per barrel corresponds to a crude-oil price of about $30.43 per barrel; this is regarded as a conservative estimate of the price of crude oil during the late 1990s and into the twenty-first century.

Operations and Maintenance (O&M) Costs. It is expected that many production wells would have to be replaced over time because of a loss of steam pressure. The useful life of a well is expected to be random, with many of the early wells having a relatively short life. However, during the first 5 years of operation, replacement wells are not anticipated because of the reserve capacity that would be available. Starting in the 2000, it is anticipated that approximately six replacement wells would be required annually. This translates into an annual cost of $15 million, based on $2.5 million per well.

As indicated above, each power plant is expected to have fifteen producing wells and three injection wells per plant. For 10 power plants, there would be 180 usable wells. At an estimated cost of $58,000 per well, the total annual O&M costs at full development would be $10.4 million. Annual O&M costs for the 10 power plants are expected to total $3.3 million for operational labor and $24.1 million for chemicals, waste disposal, and contracted maintenance. At full development, the total cost for well replacement, well-field O&M, and power-plant operational labor and O&M is estimated to be about $52.8 million per year.

Employment. As shown in Table 3.1, after construction is completed, employment is projected to total 200 jobs. Contracted maintenance would include crews which move from plant to plant to perform general maintenance and to overhaul the power plants. The general maintenance crew would include unskilled laborers for cleanup, painting and repair; the overhaul crew would include electrical, mechanical, and instrument engineers and technicians.

These employment figures assume highly automated plant operations; with less automation, operational employment could be double the figures used in this report.

Table 3.1 NUMBER AND TYPES OF OPERATIONS AND MAINTENANCE JOBS GENERATED BY A 500 MW GEOTHERMAL DEVELOPMENT

		Jobs
Well Replacement (2 crews of 12)		24
Power Plant and Well Field:		
Supervisors	2	
Engineers	2	
Operators	50	
Electricians	5	
Instrument Technicians	5	
Secretary	2	
Other (support staff)	5	
Subtotal		71
Contracted Maintenance:		
General Crew	30	
Overhaul Crew	75	
Subtotal		105
Total Jobs		200

Wages. O&M wages are estimated to total $7.1 million per year at full development, excluding benefits. This is based on average annual wages of $33,426 for construction workers (see above), $38,000 for power-plant and well-field personnel, $20,000 for the general maintenance crew, and $40,000 for the overhaul crew.

C. ECONOMIC IMPACTS OF THE PROPOSED DEVELOPMENT

1.0 Sales and Employment

Direct and total annual sales, employment, and annual wages which would be generated by the construction and operation of geothermal power are presented in Table 3.2. As indicated, construction activity is expected to generate $227 million in total annual sales, support 595 total jobs, and generate $17.8 million in total annual wages. Operations would generate an estimated $475 million in total annual sales, support 655 jobs, and generate $15.9 million in total annual wages.

2.0 Population and Housing Supported

As shown on Table 3.3, during the construction phase, geothermal power is expected to directly support 575 people and 215 homes, and directly and indirectly support a total of 1,430 people and 530 homes. Upon full operations, 480 people and 180 homes would be directly supported, and 1,570 people and 580 homes directly and indirectly supported.

3.0 Electric Rates

The impact of the proposed project on electric rates will depend upon the power contract between geothermal developers and Hawaiian Electric Company (HECO). The initial rates could be equivalent to the prevailing rates for oil at the time of contract with provisions for general inflation. The rate could be slightly higher for customers on Oahu due to transmission costs. However, in exchange for guaranteed long-term payments by HECO, it is anticipated that the electric rates will be stabilized at a rate which will, over the long term, be lower than that which would otherwise occur if the rates were to reflect world oil prices.

4.0 Fiscal Impacts to the State and County

<u>State.</u> The estimated annual revenues to the State of the proposed project are projected to be:

Excise Tax (0.5% of revenues)	$ 1.2 million
Income Tax	3.2 million
Royalties	11.2 million
Total	$15.6 million

In addition, the State would receive an estimated $80.4 million in construction-related revenues from excise tax and income tax, over the 14-year construction period, or an average of $5.7 million per year. Also, the State would receive income tax revenues from residents who are supported directly and indirectly by the project, and

Table 3.2. DIRECT AND TOTAL ANNUAL SALES, EMPLOYMENT, AND ANNUAL WAGES GENERATED

	Direct	Multiplier	Total
Construction:			
Average Annual Sales	$82.1 million	2.77	$227. million
Average Employment	240 jobs	2.48	595 jobs
Average Annual Wages	$8. million	2.23	$17.8 million
Operations:			
Annual Sales	$230. million	2.07	$475. million
Employment:			
Well Drilling	24 jobs	2.48	60 jobs
Plant Operations	176 jobs	3.38	595 jobs
Total	200 jobs		655 jobs
Annual Wages	$7.1 million	2.24	$15.9 million

Note: Total impacts include direct economic impacts, indirect impacts generated by business expenditures, and induced impacts generated by employee expenditures which are based on multipliers provided by DBED's State Economic Model.

Table 3.3 PEOPLE AND HOMES SUPPORTED BY THE CONSTRUCTION AND OPERATION OF A 500 MW GEOTHERMAL SYSTEM

	Direct	Total
Construction:		
Average Employment (jobs)	240	595
People Supported	575	1,430
Homes Supported	215	530
Operations:		
Average Employment (jobs)	200	655
People Supported	480	1,570
Homes Supported	180	580

Note: These estimates are based on 2.4 people per job and 2.7 people per home, respectively; the multipliers reflect Big Island conditions (derived from DPED 1986b).

would receive excise tax revenues on these residents expenditures. However, expenditures by the State for services and facilities required by these residents, such as schools, health services, water (well development) and highways, would offset a portion of these revenues. Because these residents are expected to earn a higher net income than the average income, the State can expect to realize an overall positive net income; i.e., overall, the net income to the State during full operations would be higher than $15.6 million per year.

<u>County</u>. For the County, the estimated property value assessment would be $1.069 billion. This is based upon construction costs of $1.149 million minus $80 million in construction costs for unusable wells. Using the County tax rate of $10 per thousand, the annual property tax revenue to the County would be approximately $10.7 million per year. No direct support services or facilities would be required for the project.

The County would also receive property tax and other revenues from residents who are supported directly and indirectly by the project. However, the County would have expenditures, such as fire, police, roads, parks, etc., to support the residents. Because residents are expected to earn a higher net income than the average income, the County can expect to realize an overall positive net income; i.e., overall, the net revenues to the County would exceed $10.7 million annually at full development. This is a very significant amount: in 1986, property tax revenues for the County amounted to only $41.4 million.

5.0 Other Economic Impacts

Additional socioeconomic impacts, including an analysis of the impact of the development on property values and sales, are discussed in Parts VII and VIII.

PART IV: PHYSICAL ENVIRONMENT

A. GEOLOGY AND SOILS

1.0 Regional Geology

The Hawaiian Archipelago is a chain of volcanoes running northwest to southeast across the Central Pacific Basin that have erupted sequentially from the sea floor. The island of Hawaii is the most southerly, the youngest and the largest land mass in the Hawaiian chain. It is constructed of ejecta of at least five volcanoes.

The youngest and most active volcanoes on the island are Kilauea (4,090 ft.) and Mauna Loa (13,677 ft.). Hualalai (8,271 ft.), Mauna Kea (13,796 ft.) and Kohala (5,480 ft.) volcanoes comprise the rest of the island and are considered to be dormant. Loihi Seamount, a submarine volcano, has recently been located off the southeast coast of the island (Macdonald et al., 1983).

Kilauea is still in its very active shield-building stage. Eruptions may continue for long periods of time or they may be sporadic, occurring at intervals of about 18 months. Volcanic activity is located at the summit caldera or along either the southwest or East Rift Zones (identified by large pit craters, ground cracks and cinder cones) which radiate out from the caldera. Kilauea is presently in an extended period of activity. Since January, 1983, activity has centered on Puu O'o in the upper East Rift Zone (ERZ) (Fluor Technology, Inc., 1987).

The rocks of Kilauea are divided into the older Hilina Volcanic Series and the younger Puna Volcanic Series. The Hilina Volcanic Series is represented by the earliest exposed lava flows and thin intercalated ash beds. Pahala ash overlies this series and separates it from the younger flows and ash deposits of the Puna Volcanic Series. Lavas of both series are composed mostly of olivine basalts (Macdonald et al., 1983).

The rocks of Kilauea are very porous and highly fractured. There is very little soil cover over most of the shield so the volcano is highly permeable to precipitation (DPED, 1986a).

2.0 Local Geology

The Puna District comprises about 15 percent of the island's 4,038 square miles and is its eastern most projection. It is a region of undissected volcanic uplands which slope away from the ERZ to low-lying fields along the sea coast. The geologically older, low-lying fields are covered with fertile soil and lush vegetation while the younger uplands are sparsely covered with immature soils and dotted with ohia.

The ERZ is a topographic crest which slices through the Puna District. It is unusual because rather than radiating straight out from Kilauea caldera, it trends southeast for 4 miles and then turns 65 degrees NE. It extends to Cape Kumukahi, the most eastern portion of the island, and can be traced seaward for an additional 70 miles. At this lowest and most eastern portion above sea level, the ridge disappears into a low-lying area consisting of a series of grabens and spatter deposits (Fluor Technology, Inc., 1987).

The ERZ, the underground conduit for lateral migration of molten lava from Kilauea's summit, is marked by several distinct physiographic features. A series of unevenly distributed pit craters are located in the upper rift area and link the rift zone to the caldera. About 60 spatter and cinder cones, two parasitic shield volcanoes and several more pit craters are found along the ERZ. Large ground cracks are located along the length of the rift as are a number of slightly eroded fault scarps. Kalapana and Kapoho are located in grabens (elongated depressions of the earth's surface caused by two or more faults). A tangental fault system which offsets the ERZ is located east of Pawai Crater in the Kapoho section (Figure IV-1).

A 5- to 15-mile-wide dike complex underlies the ERZ, and its top is located approximately 4,000 feet below the surface. The complex consists of an aggregate of closely spaced, basically parallel and nearly vertical dikes which intrude sequences of Mauna Loa and Kilauea pillow and subaerial lavas. Local magma chambers are thought to exist beneath the ERZ because high temperatures (1,000 to 1,900 degrees F) and mineral differentiation of the basalts have been reported. The Puna geothermal system is dependent upon the heat of these magma chambers for its thermal energy (Fluor Technology, Inc., 1987).

3.0 Site Specific Geology

The three sites designated for geothermal development are located on the East Rift Zone of Kilauea Volcano within established geothermal resource subzones (GRS). Two of the sites, the Kamaili Section (5,530 acres) and the Kapoho Section (7,350 acres), are located within the Kilauea Lower East Rift

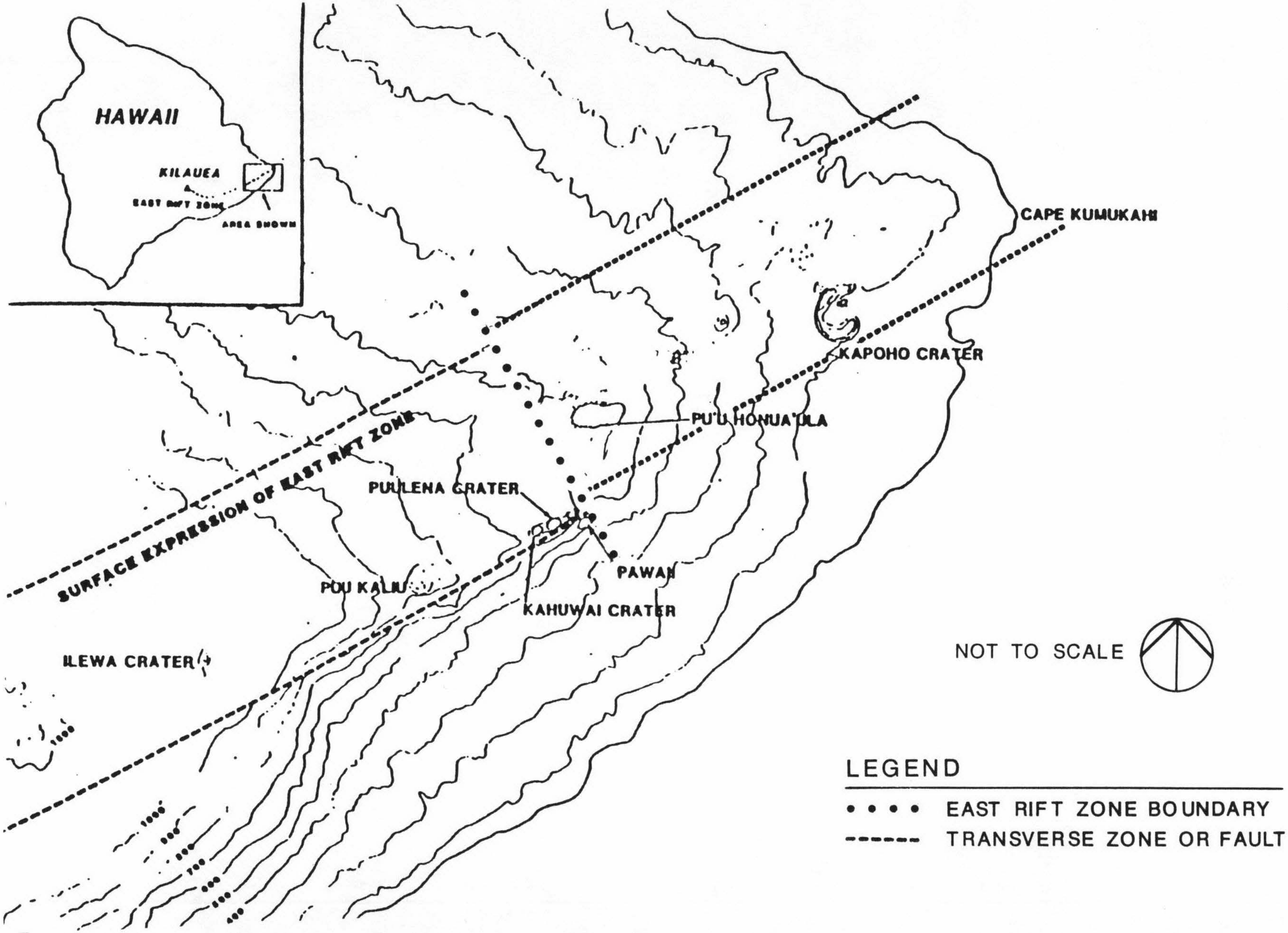


Figure IV-1

SURFACE EXPRESSION OF LOWER EAST RIFT ZONE

SOURCE: FLUOR TECHNOLOGY, INC., 1987

GRS. The third site is the Kilauea Middle East Rift GRS (9,104 acres) (DPED, 1986a). Evidence of local eruptive activity, lava flows, devastated areas and steam vents, are found in the GRS. Lavas from the 1955, 1960, 1961, 1963 and 1977 Kilauea eruptions entered the rift zone and were vented in these subzones (True/Mid-Pacific, 1986).

The Kapoho section is the most easterly section. It is about 5.5 miles long by 3 miles wide with elevations ranging from 60 feet to 650 feet. Approximately 35 percent of the section is covered by lavas erupted during the 1955 and 1960 events.

This section can be divided into three subsections. The eastern portion is covered by flows from Kapoho (1960), contains several large cinder cones and a few pit craters, and has a very gentle slope. The slope steepens slightly in the central portion where several pit craters are located as well as one of the more prolific 1955 vents. Several large ground cracks, a tangental fault system, a large cinder cone and multiple pit craters are located in the western subsection where the slope decreases slightly. Three grandfathered subzones (established by the Hawaii State Legislature in 1984), the Hawaii Geothermal Project's Well A (HGP-A), and Lava Tree State Park are located in this subsection.

The Kamaili section is centrally located and is separated from the Kapoho section by the sparsely developed Leilani Estates subdivision. Elevation ranges from 600 feet to 1340 feet, and the section is 3.8 miles long by 3.2 miles wide. Approximately 15 percent of the section is covered by recent lavas erupted in 1955.

This Kamaili section can be divided into three subsections. The northern portion has a slight slope to the north away from the rift axis and is in homesteads. The central rift axis is a flattened region with few geologic features. Most of the volcanic features such as cinder cones, pit craters, ground cracks and recent lava flows (1955) are located in the southern section where the slope drops steeply off to the south from the rift axis.

The Kilauea Middle East Rift GRS is the most westerly of the three subzones and abuts the western margin of the Kamaili section of the Kilauea Lower East Rift GRS. Elevations range from 1200 to 2000 feet, and the section is 6.4 miles long by 3.2 miles wide. Approximately 15 percent of the section is covered by recent lavas which erupted in 1961, 1963 and 1977. Most of the subzone is classified as conservation land.

This GRS can be divided into three sections. As with the Kamaili section, most of the volcanic features are located in the southern portion where the slope drops off steeply to the south, and recent lava flows (1973 and 1977), cinder cones, and Heiheiahulu Cone are located. A small 1961 lava flow and many large ground cracks are found along the flattened central rift axis. The slope of the northern section steepens slightly to the north where a few large ground cracks are located.

4.0 Geothermal Resource

In order for a geothermal area to have resource potential at our present state of technology, a potential reservoir must have a temperature greater than 125 degrees C at depths less than three kilometers. The reservoir must consist of a permeable zone that permits adequate recharge of water to the reservoir, and an adequate supply of water for recharging must be available (DPED, 1986a).

There is a greater than 90 percent chance of finding low temperature (50 degrees C - 125 degrees C) and high temperature (>125 degrees C) resources at depths less than 3 km for the entire Kilauea ERZ. This statement is based on regional qualitative interpretation of the following types of data: groundwater temperature; geologic age; geochemistry; resistivity, infrared, seismic, magnetic, gravity, and self-potential surveys; and exploration drilling. Only exploration drilling, however, is capable of positively identifying a subsurface geothermal system (DPED, 1986a).

The prolonged activity at Pu'u O'o demonstrates that vast and steady amounts of heat energy are available from Kilauea volcano (True/Mid-Pacific, 1986). Continued successful generation of electricity at the HPG-A plant confirms the resource potential of the ERZ.

A large source of water supplies the geothermal system. Precipitation in the range of 100 inches per year falls over the ERZ. It is possible that seawater intrudes a portion of the rift zone (True/Mid-Pacific, 1986). These two sources provide a more than adequate supply of water to the geothermal system.

There is a preponderance of evidence that geothermal resources exist along the ERZ and in the GRS. Also, there is little if any change in the surface volcanic expression from the upper to lower elevations of the ERZ (Holcomb, 1980). An assumption follows that the subsurface character will not differ accordingly.

The Puna geothermal reservoir is a two-phase (vapor - liquid) resource that is one of the hottest in the world (>600 degrees F). It consists of a dike complex in which the dikes increase in number with depth (Figure IV-2). High temperatures are maintained by high temperature dikes located over secondary magma chambers thought to be located beneath the reservoir (Fluor Technology, Inc., 1987).

The top of the reservoir is located at about 4,000 feet below the surface while the bottom of the reservoir extends to at least 7,200 feet. A relatively impermeable seal that extends upwards from 4,000 feet to about 2,000 feet below the surface caps the reservoir. A zone of vigorous qroundwater flow exists from the top of the seal to the water table which is located approximately 600 feet below the surface (Fluor Technology, Inc., 1987).

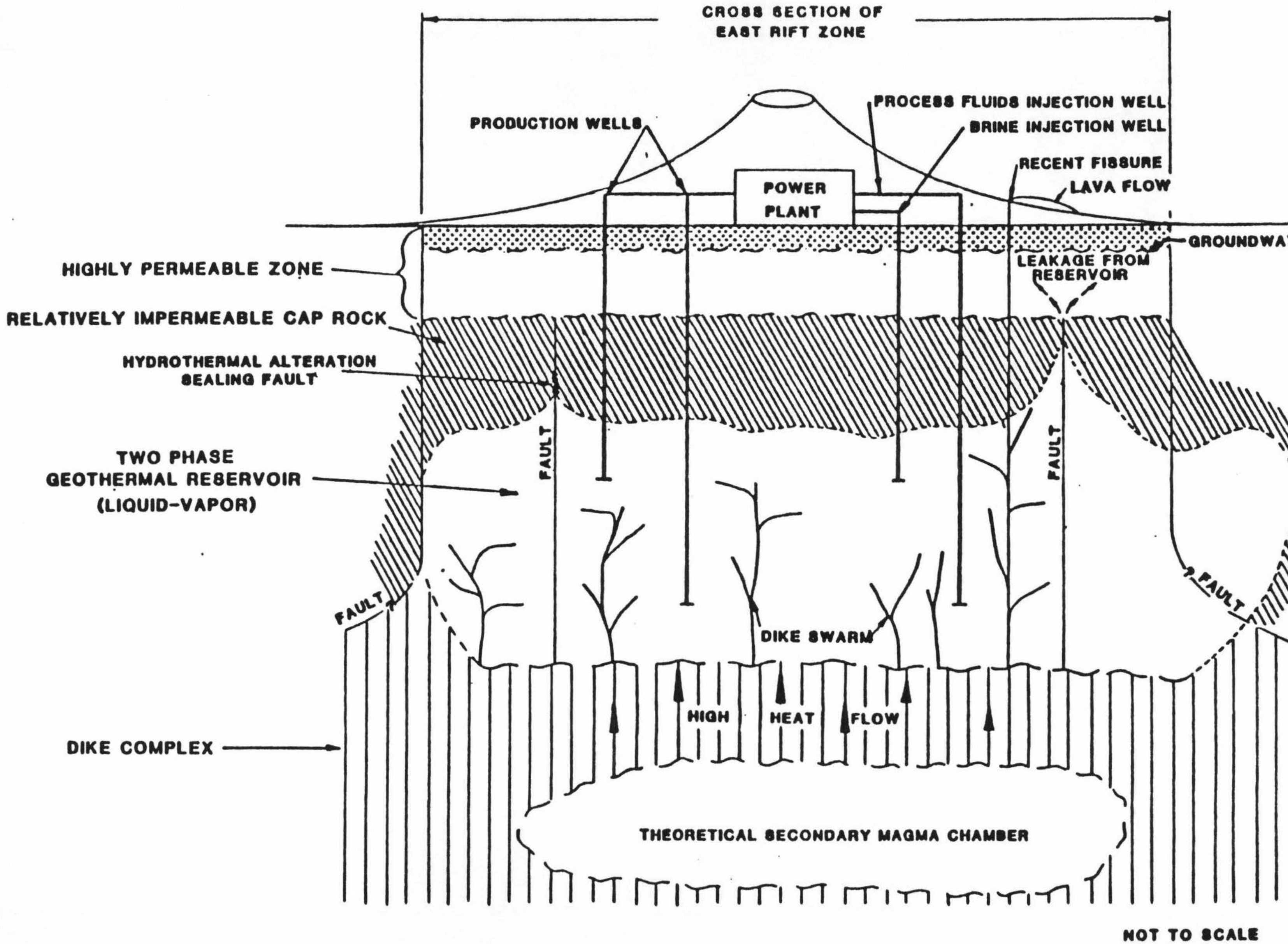
Ground water occurs in porous, permeable and secondarily fractured basalt layers. The cap rock is relatively impermeable but leakage of geothermal fluid into the ground water occurs where the seal is locally broken by geologic structure. The amount of fluid escaping from the cap rock is sufficient to completely alter the fresh water character of the ground water in some locations (Fluor Technology, Inc., 1987).

Four productive geothermal wells have been drilled into the geothermal reservoir: HGP-A, KS-1 (Kapoho State 1), KS-2 and KS-1A. Composite data for geothermal fluid chemical composition and noncondensable gas composition from these wells are presented in Tables 4.1 and 4.2, respectively. The HPG-A well is capable of generating approximately 3 megawatts of electricity and has demonstrated the use of the geothermal fluids as an energy source for electricity generation (Fluor Technology, Inc., 1987).

5.0 Geologic Hazards

The Hawaiian Islands were and are being built by volcanic eruptions which are potentially dangerous to people and property. There are two different types of hazards associated with volcanic eruptions: those that endanger people and property directly such as lava flows, tephra falls, volcanic gases and pyroclastic surges; and those that are an indirect result of volcanic activity such as earthquakes, tsunamis, ground fractures and subsidence. Tsunamis are of little or no consequence to the subzones because they do not extend to the shoreline.

Volcanic-hazard zone maps which distinguish zones of differing magnitude of several different hazards have been prepared for Hawaii by Mullineaux et al., (1987). The following discussion is based on these volcanic-hazard zones.



ITEM	DEPTH BELOW GRADE
WATER TABLE	~ 600'
TOP OF CAP ROCK	~2500'
TOP OF GEOTHERMAL RESERVOIR	~4000'

Figure IV-2

CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL RESERVOIR

SOURCE: FLUOR TECHNOLOGY, INC., 1987.

Table 4.1 GEOTHERMAL FLUID CHEMICAL COMPOSITION COMPOSITE DATA[a]

Element	Brine[b] (ppm(w))	Steam Condensate[b] (ppm(w))
Na	600 - 10,000	0.17
K	123 - 2,700	0.10
Ca	40 - 920	0.10
Mg	1 - 2	<0.1
Fe	<1 - 8.4	0.05
Mn	<1 - 8.5	--
B	4 - 11	<0.05
Br	40 - 80	--
I	<20	--
F	0.2 - 0.9	--
Li	1 - 9	<0.01
Cl	925 - 21,000	<2
NH_3	<0.01 - 0.1	0.12
SO_4 (c)	9.2 - 24	13
Hg	<0.001 - <0.05	--
As	0.09 - 0.4	<0.01
S= (d)	5 - 100	--
Total Alkalinity	<10	<10
HCO_3	0 - 18	0
CO_3	0	0
SiO_3	420 - 1,500	0.7
TSS	70	--
TDS (e)	2,500 - 35,000	15
pH	<5 - 5.5	3.5
Conductivity (mho/cm)	3,100 - 67,000	120
Density	1.03	--

[a] Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.

[b] Wellhead pressure (WHP) = 155 psig; Wellhead Temperature (WHT) = 368°F.

[c] Concentration high due to oxidation of S= to SO_4.

[d] Concentration low due to oxidation of S= to SO_4.

[e] TDS = Total Dissolved Solids.

Source: Fluor Technology, Inc. (1987)

Table 4.2 NONCONDENSABLE GAS COMPOSITION COMPOSITE DATA[a]

Gas	Observed Steam Content ppm(w)	Plant Design Composition ppm(w)
CO_2	250 - 1,042	956
H_2S	800 - 1,300	1950
NH_3	(c)	-
Ar	6 - 13	-
N_2	10 - 700	582
CH_4	(d)	-
He	<0.009	-
H_2	11 - 140	12
Total NCG	1,500 - 2,200	3500

[a] Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.
[b] WHP = 155 psig; WHT = 368°F.
[c] Below Detection Limit (<1.5 ppm NH_3 in KS-1A).
[d] Below Detection Limit (<0.2 ppm CH_4 in KS-1A).

Source: Fluor Technology, Inc. (1987)

Direct volcanic hazards include the following:

Lava Flow Hazards. Lava flow hazard zones are based on lava-flow coverage of different areas during specific time periods. The Island of Hawaii is divided into nine hazard zones, and the three geothermal resource subzones are located in Zone 1 which is the highest risk zone. Zone 1 is defined by Mullineaux et al. (1987) as, "the summit areas and active parts of the rift zones of Kilauea and Mauna Loa; in those areas, 25 percent or more of the land surface has been covered by lava within historical time, during the 19th and 20th centuries. These areas contain the sites of most historic eruptions, and a large majority of lava flows that will affect other zones in the near future probably will originate in zone 1."

Island volcanoes are constructed of lava flows characterized by very fluid lavas capable of spreading great distances from the vent. Two types of lava, a'a and pahoehoe, are recognized based on contrasting flow behavior and surface features. A'a flows are thicker and more viscous than pahoehoe flows. Hawaiian lava flows range in length from a few yards to more than 35 miles, while flow width varies from a few feet to 2.5 miles.

Even though lava flows are usually thin, about one meter thick near the vent, a structure more than five meters high is not immune to burial by lava. Many flow units are usually generated by a single eruption, and these flows will superimpose one upon another. Thus, in the vicinity of the vent, accumulations over 10 meters thick are not uncommon.

Lava flows are more of a hazard to property than to human life for they normally move slower than walking speed. Lava moving down a steep slope, however, has been clocked at speeds as fast as 30 mph. The real danger is to stationary property. A'a lava flows that have moved far from the vent tend to bulldoze, crush, bury and burn any structure in their path. Pahoehoe lava flows tend to flow around objects. In theory, it is possible for a pahoehoe flow to enter a structure, ignite the flammable materials, and soften and distort some of the metalwork. Then, the cooled lava can be removed and the building reoccupied.

Cooled lava can be removed provided the eruption is fairly short and the flows are thin and friable. A problem with thicker flows is that the crust tends to insulate underlying lava, and cooling time increases exponentially with flow thickness. It could take many months to recover from a long eruption that produced thick flows.

Summit swelling and increasing swarms of volcanic earthquakes can warn of impending eruptions. Past volcanic activity can suggest future activity. Accurate predictions of short-term probabilities of lava-flow coverage for any specific area, however, are clearly not yet feasible (Mullineaux et al., 1987).

Tephra Fall or Pyroclastic Fallout Hazard. An additional volcanic hazard is tephra or pyroclastic fallout. Tephra falls are events in which ash- to cobble-sized molten and solid rock is thrown into the air by lava fountains, magmatic eruptions or phreatic explosions. Spatter, cinder and littoral cones are constructed of the larger pieces while smaller particles are carried downwind forming widespread ash deposits. These events are frequent but generally do not pose a hazard to people. Property and vegetation, however, can be seriously affected. Severe damage is usually limited to areas less than 2 kilometers from active vents.

Proximity to the coast increases the probability of an eruption being powerfully explosive and producing massive amounts of debris. If a vent is within one kilometer of the coast, the probability is close to 100 percent. The explosiveness is caused when steam is generated from magma contacting near-surface groundwater. Lung irritation, poor visibility, anxiety, blockage of escape routes and severe cleanup problems are other dangers from tephra falls.

Pyroclastic Surge Hazard. Pyroclastic surges are infrequent events but do pose a severe hazard to people. They are hot (>100 degrees C) clouds of ash, gases and rock fragments usually generated by steam explosions or by explosions of magma and steam that move laterally away from a source vent at high rates of speed (>35 mph). Surges decelerate rapidly and typically stop within 10 miles from the source. Therefore, the higher hazard areas are those closest to the vent.

A single pyroclastic hazard zone has been determined for Kilauea Volcano, the caldera and an area extending 10 kilometers from its center. Pyroclastic surges could take place anywhere that ground or sea water interact with magma. Thus, it is conceivable that it could happen where the rift zones encounter the shoreline or anywhere along the rift where ground water is encountered.

Asphyxiation by hot ash, impact by rock fragments traveling at high speed and burns from hot, clinging ash are the chief hazards to people. Pyroclastic surge hazards to property are impact and blast effects.

Vegetation and structures can be burned, buried and abraded.

Volcanic Gas Hazard. Volcanic-gas emissions from the vent areas are continuous but are a relatively minor hazard to people and property. Water vapor, sulfur dioxide and carbon dioxide are the most abundant constituents of volcanic gas in Hawaii. Various combinations of sulfur, oxygen and hydrogen, such as hydrogen sulfide and sulfur dioxide, are the gases of most concern to human health. Carbon dioxide is heavier than air, can collect in depressions and can cause asphyxiation.

The hazard is greatest downwind from an active vent area. Hazard zones are the same as those for tephra falls, the caldera and along the rift zones. They are wind driven and their effects decrease with distance from the vent.

Volcanic gases combine with water (rain) forming sulfuric acid which can damage live tissue, cloth and metals. Brief exposure to volcanic gases by healthy people generally is not harmful. People with lung or heart ailments are in danger when exposed to gas emissions. Kilauea recently (June, 1987) claimed its first victim in many years when a woman with lung disease died after exposure to gas emissions at the Halemaumau Fire Pit. Many types of plants cannot live in areas where volcanic gases are emitted. Some are so sensitive that they cannot live within 30 kilometers of a source.

Indirect volcanic hazards include the following:

Seismic Hazard. The island of Hawaii is an area classified as Zone 3, the highest risk zone on the Seismic Probability Map published by the Seismological Society of America. In 1975, one of the largest earthquakes to be recorded in the state occurred as magma was injected into the rift zone of Kilauea. The flank of the volcano was shoved outward, and the earthquake was generated when a portion of the south flank subsided along the Hilina Fault System. The earthquake had a magnitude of 7.2 on the Richter Scale (Tilling et al., 1976).

Earthquakes occur in the thousands each year in the state of Hawaii and most of them occur on the island of Hawaii. They are generally volcanically related, and are the result of magma moving at shallow depths in association with volcanic eruptions. Most earthquakes are generated at the summit area or along the rift zones of an active volcano. A few earthquakes originate within or at the base of the volcano, and some of these are probably generated in the crust of the earth beneath the volcano. Such earthquakes are considered to be tectonically related (Mullineaux et al., 1987).

Both people and property are directly endangered by earthquakes which cause landslides, shaking of structures, and ground fracturing and settlement. In the past, earthquakes have disrupted water, sewer and telephone lines, and damaged buildings, water tanks and bridges.

Surface Deformation Hazards. Surface deformation in Hawaii is generally caused by magma movement resulting in ground swelling and horizontal extension of the surface, which in turn causes fissuring and normal faulting. In the summit areas and along the rift zones of active volcanoes, fractures caused by magma movement are numerous. Deformation occurs prior to volcanic events such as eruptions or magma intrusion at depth. A failed dike can be expressed at the surface by a large ground fracture or crack (DPED, 1986a). Ground shaking, caused by earthquakes or gravitation subsidence, can trigger a large landslide or form a graben.

Ground fractures pose a minor but persistent danger to people and animals. Cracks can form slowly or rapidly. A crack that opens suddenly could trap somebody. It would pose a hazard as long as it is opened. Often, large cracks are hidden by thick vegetation. Potential property damage from ground cracks includes damage to roads, buildings, and utility lines (telephone, water, electric, gas and sewer).

Volcanically or tectonically caused subsidence in Hawaii is usually associated with volcanic rift zones. Magma injection into the volcano causes the flank to inflate and become destabilized. Eruption or withdrawal of magma causes further instability by removing underlying support of the surface. Large blocks may slump along a fault system, grabens may form when a block subsides between two faults, pit craters may form as lava is withdrawn, or a lava tube may collapse (Mullineaux et al., 1987).

Subsidence does not pose much of a hazard to people but property can be endangered. Rapid subsidence may damage or destroy structures by tilting, shaking or fracturing the ground. Also, subsided areas may become more vulnerable to inundation by lava flows and water.

The three geothermal resource subzones are located in the active Kilauea ERZ where a constant source of heat (evidenced by the recent volcanic activity) creates a hazardous environment. Lava flows, explosive eruptions, ground deformation, subsidence and earthquakes are the potential hazards. Any geothermal development activity along the ERZ is subject to these hazards. In fact, any volcanically active area is subject to similar risks. Presently, successful geothermal plants are being operated in the shadow of active volcanoes in Iceland, Central America and the Philippines at considerably more dangerous locations than any in Hawaii. The challenge is to reduce the risks associated with developing a geothermal resource in an active region to an acceptable level by using adequate safeguards.

Volcanic activity producing lava flows has occurred in the ERZ historically at intervals ranging from 4 years, based on the period from 1950 to present, to about 40 years, based on the period from 1790 to 1950 (True/Mid-Pacific, 1986). Activity at Pu'u O'o, beginning in 1983, is one of the longest eruptive series and has included numerous eruptive phases spaced at intervals of a few weeks (Fluor Technology, Inc., 1987).

In the past 30 years, activity has been concentrated in the upper and lower ERZ and lava flows have entered all three subzones. Volcanic activity has been rather uniformly distributed along the entire length of the ERZ from the historic perspective (1790 to 1988). Any given plot of ground within the ERZ has approximately a 5 percent probability of being buried within a century according to historical records. It should be noted that there is no instance in the historical record of a new operative fissure occurring over a previously existing fissure (True/Mid-Pacific, 1986).

Holcomb (1980), in mapping flow ages of Kilauea volcano, found that the flows along the northern flank of the ERZ are considerably older than those of the ERZ axis and the southern flank. From a safety perspective, the less active northern flank of the ERZ appears to present a safer environment for development.

The Kamaili Section, Kilauea Lower East Rift GRS and the Kilauea Middle East Rift GRS are discussed together because of their proximity to one another for the purpose of describing the site specific geologic hazards. The Kapoho Section, Kilauea Lower East Rift Zone GRS, is geographically separate and has distinctive geologic features.

<u>Kapoho Section, Kilauea Lower East Rift Zone GRS</u>. The presence of large cinder and spatter cones aligned with numerous ground cracks, eruptive fissures, and pit craters situated within a graben indicates that the Kapoho

section is located along a section of the ERZ that has seen much recent activity. In such a region there are potential hazards from lava flows, explosive eruptions, surface deformation, earthquakes and subsidence.

In the Kapoho section, virtually all of the surface is younger than 500 years and about 45 percent is younger than 40 years. Since 1790 there have been five eruptions on the lower rift zone, an average of one every 40 years. Of those, half have been within the past 30 years. The average flow covers an area of about 11 square kilometers; the 1955 eruption generated a 16 square kilometer flow (DPED, 1986a).

Most of the recent lower rift eruptions have occurred along the southern boundary of the rift zone, as the 1955 eruptions did, or along the central axis of the zone as in the case of the 1960 Kapoho event. The risk of a site being overrun by lava from a vent located outside the site area is largely a function of topography. Sites can be impacted by lava flows produced up slope. Topography of the Kapoho section is generally flat so that the section could easily be overrun if a flow generated from up-rift reached the area. A review of historic eruptive events indicates that an average lava thickness of about 18 feet has accumulated with ranges between a few feet and 37 feet (DPED, 1986a).

During the 1960 Kapoho eruption, magma contacted groundwater causing an explosive eruption which showered the surrounding area with wet black ash. The likelihood of this type of eruption occurring increases significantly with proximity to the coast and approaches 100 percent within one kilometer from the shore (Mullineaux et al., 1987).

The hazard to property caused by arching, uplift and tilting associated with magma movement would not be significant because the deformation would not be of sufficient magnitude or acceleration. Fissuring and faulting, however, do pose a threat to property. Numerous fissure systems have been identified within the ERZ and several large fissures are located in the western portion of the section. Many of these systems have formed en echelen fissures which are individually straight and parallel to the rift margin. Since new eruptive fissures do not appear to occur over a previously existing fissure, each new eruption is accompanied by new fissuring.

Based on the average width of a fissure, the frequency of occurrence, and the dimensions of an engineered structure, there is an estimated 5 percent probability of damage to a primary structure within a given 40-year period (Fluor Technology, Inc., 1987). Linear structures, such as pipelines, are the most likely to suffer damage.

The most common type of earthquake in the ERZ is volcanically related and is usually caused by magma movement at shallow depths. Earthquakes in the ERZ have had a maximum magnitude of Ms = 5.0 on the Richter Scale. The only nearby source of tectonically related, potentially higher magnitude earthquakes is the Hilina Fault System to the southwest of the ERZ. The 1975 Kalapana earthquake (Ms = 7.2) was caused by movement along this system. Smaller magnitude earthquakes occurred in 1954 (Ms = 6.5), in 1951 (Ms = 6.5 - 6.9) and in 1929 (Ms = 6.5). On April 2, 1868, the largest historically recorded earthquake (Ms =or > 7.5) originated along the fault system near South Point (Fluor Technology, Inc., 1987).

Within the next 40 year period, a maximum earthquake of about Ms = 6.75 with an epicenter within 15 miles from the ERZ is likely and should be assumed for planning purposes. Despite the magnitude of historic earthquakes, little structural damage has occurred and acceleration has rarely exceeded 0.49 g. During the 1979 Kalapana earthquake (Ms = 7.2), an acceleration of 0.22 g was recorded at Hilo (Fluor Technology, Inc., 1987).

Subsidence due to withdrawal of geothermal fluids is of little concern because the geothermal reservoir is composed of self-supporting, dense pillow basalts overlain by subaerial lava flows. The compressive strength of these rocks is not affected by fluid removal (Fluor Technology, Inc., 1987).

Subsidence due to natural causes has some potential for damaging effects. Island settling, or regional subsidence, is estimated to occur at a rate of approximately one foot per century and poses little threat to GRS development. Localized settling of discrete blocks on the order of a few feet may occur in the ERZ within the life of a project due to subsurface withdrawal of magma. Subsidence of this type would happen in elongate, fault bounded blocks, approximately parallel to the trend of the rift zone. This possibility should be considered during the project design to block slumping along coastal margins or lava tube collapse, and should not pose a significant threat to development within the GRS (Fluor Technology, Inc., 1987).

<u>Kamaili Section, Kilauea East Rift Zone GRS and the Kilauea Middle East Rift Zone GRS</u>. There is very little change in the surface volcanic expression from the Middle

East Rift GRS through the Kamaili Section of the Lower East Rift GRS. As stated previously, the majority of volcanic activity is localized in the southern portions of the subzones as evidenced by the presence of large cinder cones aligned with eruptive fissures, pit craters and large ground cracks. Thus, the potential hazards are due to lava flows, tephra falls, surface deformation and earthquakes.

Nearly 50 percent of the land in the ERZ has been covered with historic lava flows at least once and approximately 15 percent of these two subzones has been overlain with lava since 1961. The southern portion of the Kamaili Section was invaded in 1963 by lavas which erupted in the Middle East Rift GRS. As stated previously, topography is the primary factor determining the likelihood of lava coverage. The probability that any given area within the rift zone will experience lava flows at least once in a century is 5 percent, as has been stated for the Kapoho section (True/Mid-Pacific, 1986).

During the past 30 years tephra falls at vents have built eight large cinder and spatter cones along the 32-mile length of the ERZ. Thus, there is a probability, based on historic records, that a cinder or spatter cone could be formed anywhere in the ERZ every 25 years (True/Mid-Pacific, 1986).

Large ground cracks are found along the rift axis of the Middle Kamaili Section GRS. They become more numerous with proximity to the more volcanically active caldera and are possibly surface expressions of failed dikes (True/Mid-Pacific, 1986). Again, there is the same estimated 5 percent probability of damage to a primary structure within a given 40-year period as stated for the Kapoho Section (Fluor Technology, Inc., 1987).

The earthquake potential for these two subzones is very similar to that of the Kapoho Section. Because they are located within the East Rift Zone, the volcanically related earthquake hazard is the same. Tectonically related earthquake hazards are also very similar because all three subzones are oriented similarly and located approximately 15 miles from the Hilina Fault System (Fluor Technology, Inc., 1987).

6.0 Soils

The information in this section is excerpted from U. S. Department of Agriculture, Soil Conservation Service (1973). Soil classifications for each of the subzones are described.

Approximately 35 percent of the land in the Kapoho Section of the Kilauea Lower East Rift GRS has been classified as Lava Flow A'a (rLV), Lava Flow Pahoehoe (rLW) and as Cinder Land (rCL). The soils in this section are classified as Opihikao extremely rocky muck, 3 to 25 percent slopes (rOPE); and as Malama extremely stony muck, 3 to 15 percent slopes (rMAD).

Within the Kamaili Section of the Kilauea Lower Eat Rift GRS about 30 percent of the land has been classified as Lava Flow A'a (rLV), Lava Flow Pahoehoe (rLW) and as Cinder Land (rCL). The majority of the soils in this section have been classified as either Keaukaha extremely rocky muck, 6 to 20 percent slopes (rKFD), or as Papai extremely stony muck, 3 to 25 percent slopes (rPAE). Small sections are classified as Malama extremely stony muck, 3 to 15 percent slopes (rMAD); as Opihikao extremely rocky muck, 3 to 25 percent slopes (rOPE); as Olaa extremely stony silty clay loam, 0 to 20 percent slopes (OlD); as Olaa silty clay loam, 0 to 10 percent slopes (OaC); and as Panaewa very rocky silty clay loam, 0 to 10 percent slopes (PeC).

The majority of the soils in the Kilauea Middle East Rift GRS have been classified as Keei extremely rocky muck, 6 to 20 percent slopes (rKGD). Small sections are classified as Kiloa extremely stony muck, 6 to 20 percent slopes (rKXD) and as Papai extremely stony muck, 3 to 25 percent slopes (rPAE). About 15 percent of the land has been classified as Lava Flow A'a (rLV) and as Lava Flow Pahoehoe (rLW).

7.0 Impacts and Mitigation on the Geothermal Reservoir

The performance of geothermal reservoirs over time and the possible depletion or cooling of the resource are major uncertainties in geothermal development. It is not known, at this time, whether tapping a geothermal reservoir for production is an irreversible commitment of the heat resource. Although temperature fluctuations have been observed in geothermal production wells throughout the world, the variations are attributed largely to cooler water recharging the reservoir and not to a change in the heating potential of the reservoir (Fluor Technology, Inc., 1987).

The island of Hawaii is one of the most active volcanic regions in the world. The GRS are located in the East Rift Zone (ERZ) of the Kilauea Volcano, the most active center on the island. It is extremely improbable that removing the relatively small amount of heat energy needed to meet the power plant requirements will have a significant cooling effect on the geothermal resource, which is periodically renewed by new magmatic movements. It is also improbable that the reservoir will dry out because of the highly permeable rock surrounding it, the high rainfall in the Puna District, and the hydrologic conditions of the island (Fluor Technology, Inc., 1987). Leakage from the overlying groundwater, combined with reinjection, would replace any net losses of geothermal fluid.

It has been determined that over time, the chemical composition of the HGP-A fluids has changed considerably. The total dissolved solids contents of the fluids produced by the well has steadily increased. This is believed to be caused by migration of the flash front into the formation or by an increase in the seawater component of the reservoir. The increase is likely to continue at a fairly constant rate until the flash front stabilizes. Steam production occurring in the formation is inducing silica deposition within the production aquifers. This suggests that over time, aquifer permeability may be compromised. However, the toxic transition element concentrations in the fluids from HGP-A well are likely to remain relatively low compared to continental geothermal systems (Thomas, 1982).

8.0 Impacts and Mitigation of Geologically Related Hazards

Earthquakes. Abatement procedures for seismic hazards are well known from experience in other parts of the world where seismic hazards exist. Based on this experience, Towill (1982a) suggests a design criteria of 0.5g vertical acceleration with peak amplitude at about 4 Hz and having a maximum particle motion perpendicular to the rift zone. Critical equipment would be designed to Seismic Zone 4 requirements, which exceeds the State of Hawaii Zone 3 requirements. The axis of the generator would be aligned approximately parallel to the rift system. Moreover, the turbine would be automatically shut down until evaluation of the cause could be obtained if abnormal vibrations should occur within the turbine generation system (Fluor Technology, Inc., 1987).

Volcanic Eruption. Abatement procedures against volcanic eruption hazards consists of: (1) locating all major facilities north of the active rift zone (the southern part of the ERZ), preferably on high ground; (2) constructing barriers on the uphill side of the facilities; (3) placing major facilities on raised platforms; and, (4) placing critical components in buried cellars that lava cannot enter.

The preferable procedure for power plants would be procedure #1, while the wellheads could best be protected by procedures #3 and #4. Close and continuing coordination with the Hawaii Volcano Observatory would be important in order to assure that the operator is aware of any impending conditions for which early warning would enhance the safety of personnel and equipment in the project areas (Towill, 1982a).

Ground Subsidence. Ground subsidence appears unlikely because the dense basaltic rocks from which the geothermal fluids are withdrawn are self-supporting. Also, high rainfall is continuously recharging the reservoir (Towill, 1982a).

The potential impact of subsidence due to natural faulting can be mitigated by constructing power plants outside of the active rift zone, the southern part of the ERZ. Added safety requires that power plant design provide for leveling correction of the turbine and that adequate end thrust bearings be installed (Towill, 1982a).

Induced Volcanic and Seismic Activity. Finally, there has been some concern expressed regarding the possibility of geothermal development causing or inducing volcanic or seismic activity. Because of the basic structure of Hawaiian volcanoes and the general progressive pattern of eruptions, drilling into a geothermal reservoir or into a magma body itself would not in any way be sufficient to trigger an eruptive outbreak on the flank of the volcano or at its summit (Thomas, 1982a).

The question of whether drilling activity can trigger a seismic event is somewhat more complex. There are well documented reports of seismic activity being generated by pumping fluids into subsurface clay aquifers in continental areas. This type of occurrence is considered to be highly unlikely in Hawaii because the subsurface rocks are self-supporting basalts already saturated with water. Thus, injection of water into the subsurface environment, as may be required for brine disposal, would simply displace water already there and would not act as an added lubricant. It is considered highly unlikely that drilling or brine withdrawal and reinjection in Hawaii's geothermal systems could cause seismic activity of any perceptible magnitude (Thomas, 1982a).

The seismicity of the Puna District is well documented both before and after completion of the HGP-A well. Microearthquakes in the Kilauea region have usually been attributed to the movement of magma or geothermal fluids at depth. Recently, scientists at Hawaii Volcano Observatory (HVO) have hypothesized that earthquake activity in the HGP-A region may be due to movement along a fault (the transverse break) that crosses the LERZ in this area. If this is the case, geothermal development could have some effect on seismicity, perhaps by inducing fault movement (Feldman and Seigel, 1980).

Worldwide experience with geothermal developments shows that a relationship often exists between geothermal wellfield development and increased seismicity and subsidence. When increased seismicity coincides with geothermal development, the magnitude is less than 4.0 on the Richter scale. These seismicity levels are minor events compared to the November 1975 earthquake (Ms=7.2), the largest in the southern Puna District in recorded history. No damage was reported in the Pahoa and Kapoho areas as a result of this earthquake. Seismic events, which are caused by changes in the hydrologic and tectonic balance in and around the geothermal reservoir, are not of a sufficient magnitude to cause significant surface damage (Fluor Technology, Inc., 1987).

Self-supporting basaltic lava flows and dikes make up the rock of the geothermal reservoir. The top of the reservoir is at a great depth, at least 4000 feet below the surface. In the project areas, subsidence due to geothermal production would not be expected to be a matter of concern (Fluor Technology, Inc., 1987).

B. METEOROLOGY AND AIR QUALITY

1.0 Meteorology

The island of Hawaii lies well within the belt of northeasterly trade winds generated by the North Pacific high pressure cell located to the northeast of the island. The climate of Hawaii is greatly influenced by the local topography. These terrain influences include large variations in rainfall with elevation, persistent northeasterly winds in exposed trade wind areas, and uniform diurnal and seasonal temperatures in areas near sea level.

Long-term climatological information in the vicinity of the GRS can be obtained from data collected at Hilo where weather data has been compiled by the National Weather Service (NWS) for over 40 years. The monitoring site is on the coast approximately 25 kilometers (km) northwest of the proposed geothermal development areas. These data are summarized to give a general overview of the longer term climate in the region. Recent records of site-specific monitoring data are also presented.

Mean annual rainfall on the island of Hawaii, except for the semi-sheltered Hamakua district, increases from 2500 millimeters (mm) or more along the coasts to a maximum of over 7600 mm at elevations of 600 to 900 meters, and then decreases to about 380 mm at the summits of Mauna Kea and Mauna Loa. The GRS are located in a region where prevailing northeast trade winds are lifted over the island topography, which orographically induces cloudiness causing precipitation to occur throughout the year.

Due to the island's proximity to the equator and mid-ocean location, there is little seasonal variation in weather, although winter and spring have slightly more precipitation than the summer and fall months. Approximately 60 percent of the average rainfall of 3300 mm occurs during the six month period between November and April. In Hilo, where rain falls about 280 days per year, average rainfall varies from about 3300 mm per year near the shoreline to as much as 5100 mm in mountain sections. The wettest part of the island, with mean annual rainfall exceeding 7600 mm, lies about 10 km upslope from the Hilo city limits.

Mean monthly temperatures average about 23.1 degrees C. Hawaii's uniform temperatures are associated with its mid-ocean location and the small annual variation in sun angle and solar energy. At Hilo, the range in average temperature from February and March, the coldest months, to August, the warmest month, is only 2.9 degrees C. The average daily range is 8.6 degrees C. The highest temperature of record at Hilo Airport is 34.4

degrees C with a record low of 11.7 degrees C. Greater temperature variations occur in localities with less precipitation and cloudiness, and temperatures in the mid-30s (degrees C) and less than 10 (degrees C) are uncommon near sea level.

The trade winds prevail throughout the year, although they may be absent for days or even weeks at a time. Most of the western portion of the island is sheltered from the trades by high mountains. The eastern portion of the island, where the geothermal development areas are located, is more directly exposed to the trade winds, although local mountain circulations affect wind patterns significantly. For example, the prevailing winds at Hilo Airport are not the northeasterly trades, but the southwesterly winds that flow downslope off Mauna Loa during the night and early morning hours.

Except for periods of heavy rains, severe weather rarely occurs. Thunderstorms average only 8 per year, and are rarely severe. During the winter, cold fronts or the cyclonic storms of subtropical origin (the so-called Kona storms) may bring blizzards to the upper slopes of Mauna Loa and Mauna Kea, with snow extending at times to elevations of 2700 meters or lower with icing near the summit.

Meteorological data more representative of the geothermal resource subzones have been collected since March 1981 at the Woods site in the vicinity of the HGP-A well site. This site is shown in Figure IV-3 along with other air quality monitoring sites in the region. The Woods data include hourly observations of temperature, wind speed and direction, relative humidity, precipitation, insolation, and standard deviation of wind direction fluctuation (sigma-theta). From February 1982 through January 1983, observations were recorded every three hours at this site. A summary report of prior air quality and meteorological monitoring for the Kilauea East Rift Zone was prepared for the State in 1985 (DPED, 1985).

Since the Woods data set contains the most complete set of local data, several analyses have been performed on the Woods data for past projects. Recent meteorological data collected at the Woods site is presented in Table 4.3. Annual wind roses for the period of May 1981 to May 1982 are presented in Figures IV-4 through IV-6. These figures represent wind roses for all hours, daytime hours, and nighttime hours, respectively (Fluor Technology, Inc., 1987). The wind rose for all hours, presented in Figure IV-4, shows that westerly (nighttime drainage) winds occur with the greatest frequency with the northeast trades occurring with the second greatest frequency. Figure IV-5 shows that the northeast trade winds prevail during daylight hours. During the nighttime hours, westerly drainage winds prevail as shown in Figure IV-6. A second annual wind rose, prepared for

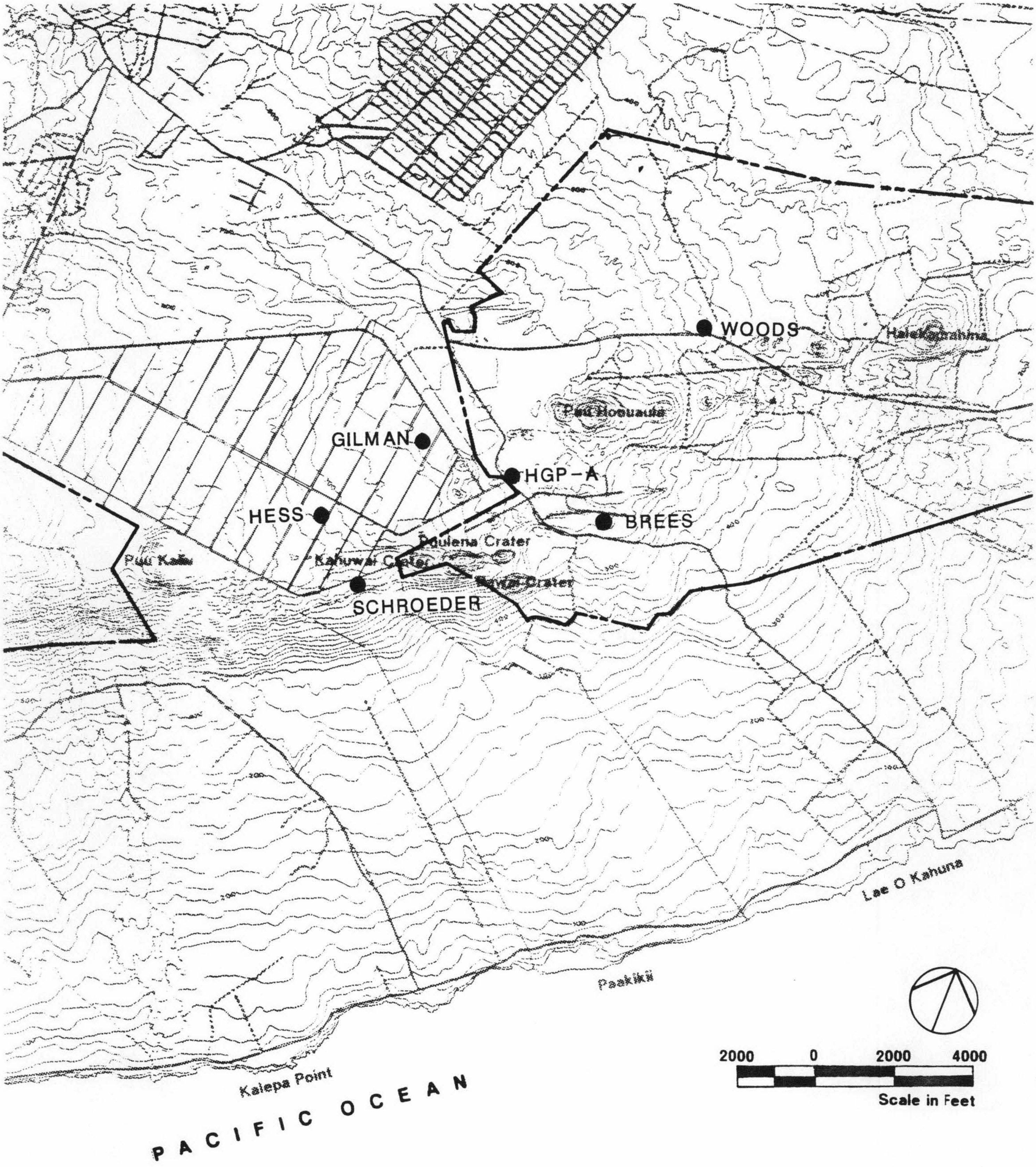


Figure IV-3

AIR QUALITY MONITORING STATIONS

Table 4.3 WOODS SITE MONTHLY METEOROLOGICAL DATA SUMMARY

Month	Temperature (Degree Centigr.)			Wind				Precipitation[a]			Relative
				Prevail.	Speed m/sec			mm	mm/day		Humidity
/Year	Avg	Min	Max	Direct.	Avg.	Min.	Max.	Total	Min	Max	(%)
NOV86	22.4	19.8	24.8	N	2.7	1.9	4.2	499	0	94	89
DEC86	20.5	18.7	20.8	NNW	2.4	1.4	4.7	99	0	13	88
JAN87	20.2	18.6	23.3	NW	3.0	1.4	6.1	139	0	52	93
FEB87	20.1	18.4	22.8	NNW	2.7	1.7	4.7	92	0	25	89
MAR87	20.2	19.2	23.5	NW	2.9	1.0	4.6	90	0	36	82
APR87	20.6	19.4	23.8	WNW	2.7	2.0	4.5	161	0	42	88
MAY87	23.0	18.2	24.5	NW	2.7	1.1	4.2	175	0	47	93
JUN87	23.1	22.0	25.2	N	2.5	2.0	3.5	145	0	20	95
JUL87	23.2	22.7	25.1	NNW	2.4	1.8	2.9	381	0.3	194	96
AUG87	24.4	24.1	26.8	NW	2.3	1.7	3.0	71	0	13	94
SEP87	24.8	23.5	26.2	NNW	2.2	1.4	3.2	103	0	59	95
OCT87	23.5	21.1	24.8	NW	1.8	1.4	2.2	118	0	60	94
EXTREME AVERAGE	22.2	21.1	26.8	NNW	2.5	1.0	6.1	2072	0	194	91

[a] = Possible malfunction of rain gage during measurement period. Rain gage sensor cable replaced October 28, 1987.

Source: Fluor Technology, Inc., 1987.

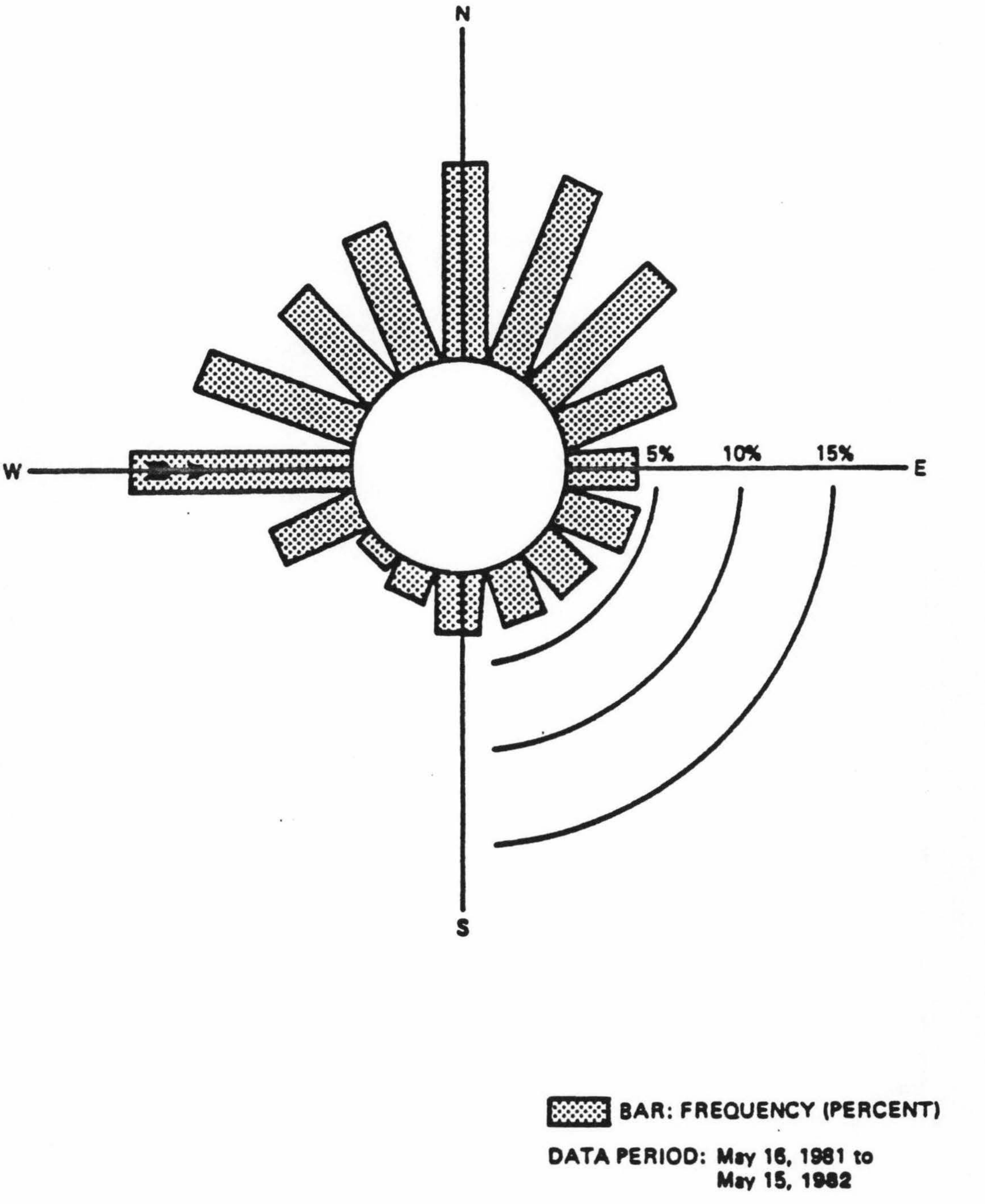


Figure IV-4

ANNUAL WIND ROSE FOR THE WOODS SITE, MAY 1981 TO MAY 1982

SOURCE: FLUOR TECHNOLOGY, INC., 1987.

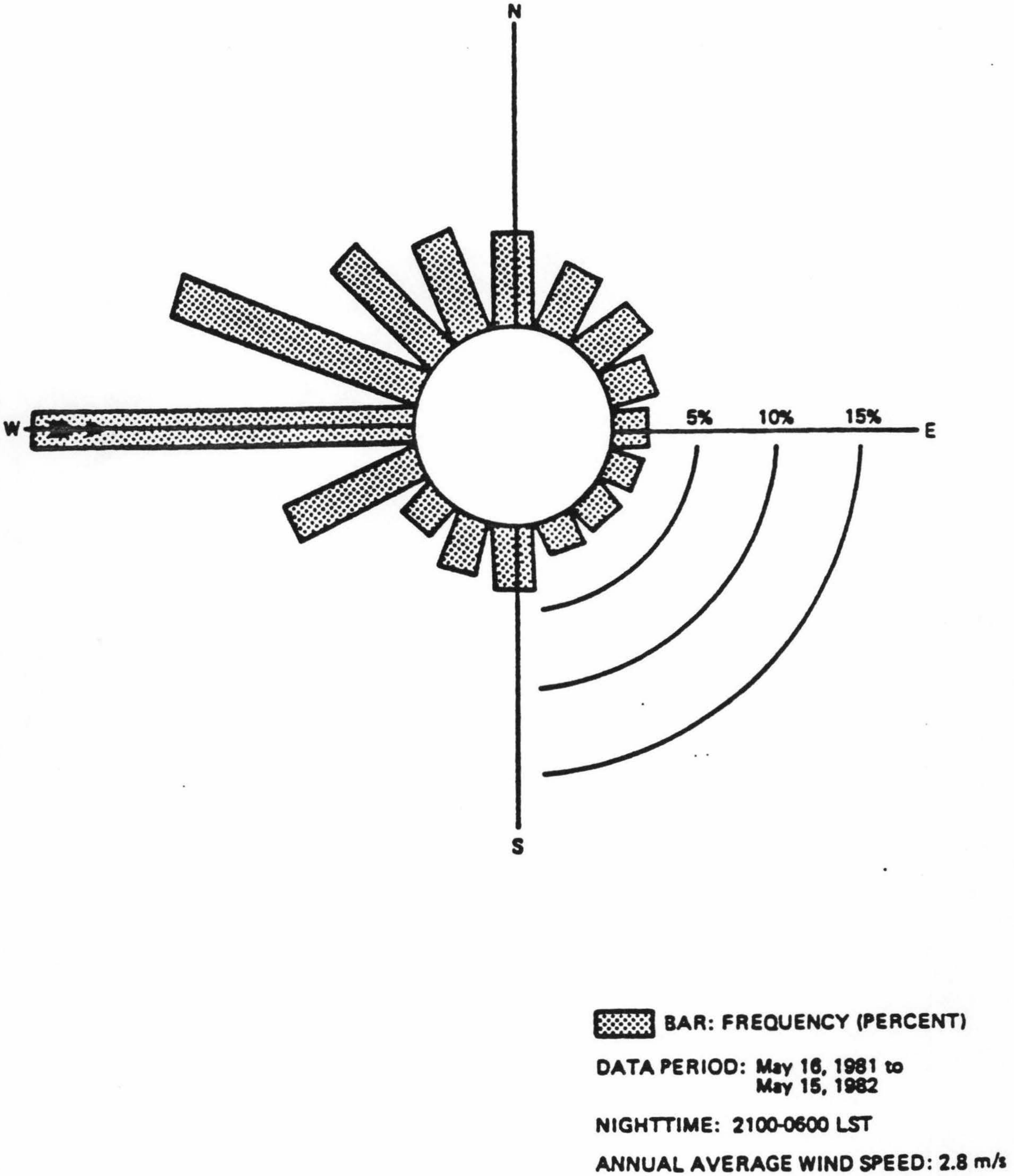


Figure IV-5

ANNUAL NIGHTTIME WIND ROSE FOR THE WOODS SITE, MAY 1981 TO MAY 1982

SOURCE: FLUOR TECHNOLOGY, INC., 1987.

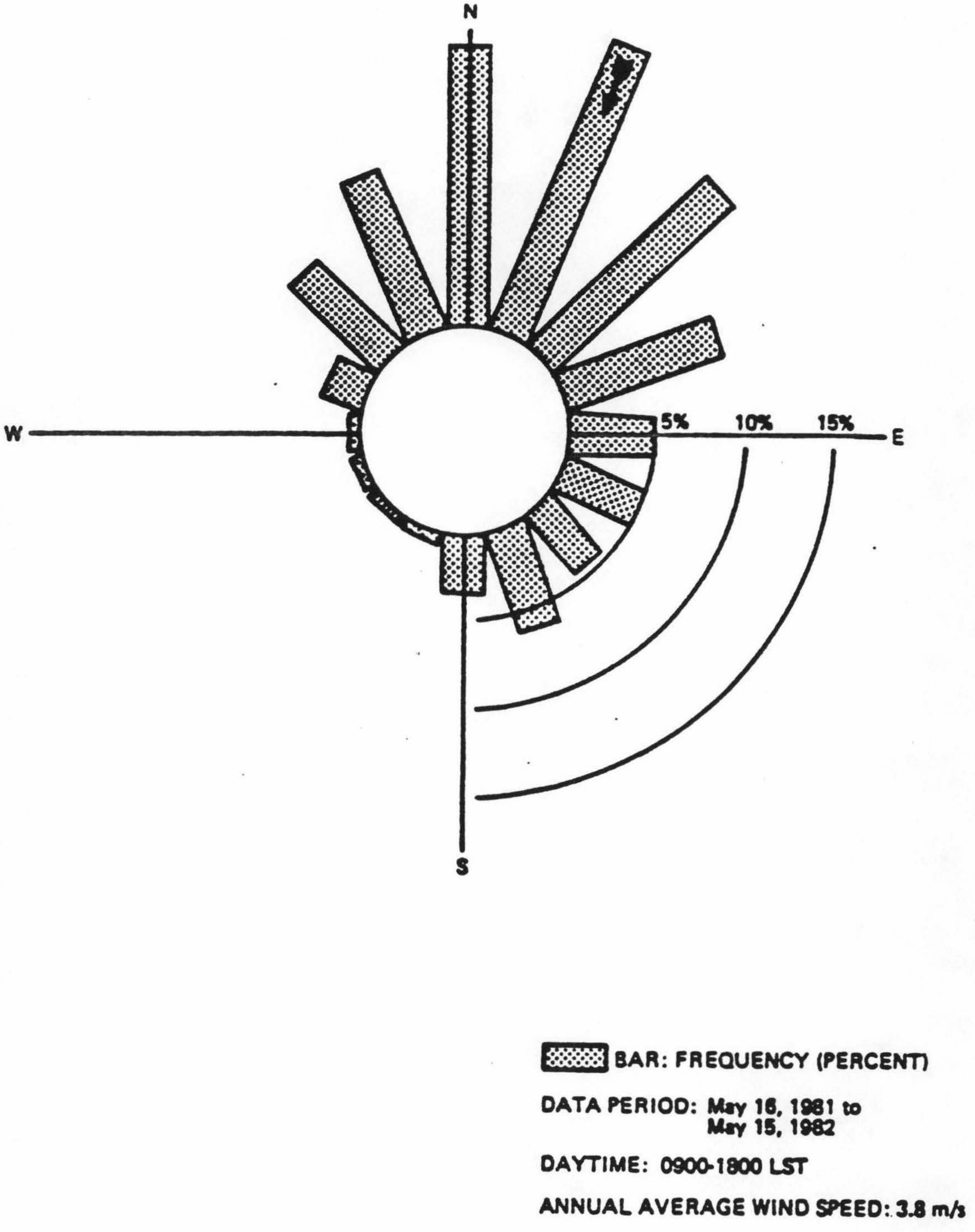


Figure IV-6

ANNUAL DAYTIME WIND ROSE FOR THE WOODS SITE, MAY 1981 TO MAY 1982

SOURCE: FLUOR TECHNOLOGY, INC., 1987.

the period of October 1982 through September 1983, is presented in Figure IV-7. This wind rose shows a similar wind direction distribution as the wind data discussed above.

The annual average wind speed for all hours is 3.3 meters per second (m/sec), while daytime wind speeds average 3.8 m/sec and nighttime wind speeds average 2.8 m/sec (Fluor Technology, Inc., 1987). Wind speeds averaged about 2.0 m/sec for all directions, with the strongest winds (3.7 m/sec) infrequently originating from the southwest. On a daily basis, winds were strongest (4.0 m/sec) in mid-afternoon, and the lightest (2.0 m/sec) between the hours of 8 and 11 in the evening.

Atmospheric stability data can be estimated from sigma-theta measurements at the Woods monitor. Stability is a measure of the amount of turbulence present in the atmosphere, and greatly affects the amount of dispersion, or dilution, of any emitted pollutant. Pasquill-Gifford stability classes were derived from sigma-theta measurements according to U.S. Environmental Protection Agency (U.S. EPA) guidelines, with adjustments to nighttime stability classes as recommended by the U.S. EPA. These classes range from Class A, the most unstable, to class F, the most stable. Class D indicates neutral stability conditions. Atmospheric mixing, and hence dispersion, is greatest during unstable conditions.

On an annual basis, neutral atmospheric conditions (Class D) occurred over 50 percent of the time. Slightly unstable conditions (Class B and C) occurred approximately 25 percent of the time. Slightly stable conditions (class E) occurred 20 percent of the time while extremely stable (Class F) or unstable (Class A) conditions occurred less than 4 percent of the time.

Mixing heights in the area can be determined from twice daily upper air soundings taken at Hilo Airport. Daily morning and afternoon mixing heights at Hilo were available from the National Weather Service for 1979. Table 4.4 presents monthly average mixing heights at Hilo based on the 1979 soundings and show that mixing heights in the area are highest in the summer and lowest in the winter. Average morning mixing heights range from 883 meters to 1555 meters. Average afternoon mixing heights range from 909 meters to 1999 meters.

2.0 Air Quality

The State of Hawaii has promulgated air quality standards to protect public health and welfare and to prevent the significant deterioration of air quality. These air quality standards are presented in Table 4.5 and cover Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Total Suspended Particulate Matter (TSP), Sulfur Dioxide (SO_2), and Ozone (O_3). Standards specified for twelve-month periods or calendar

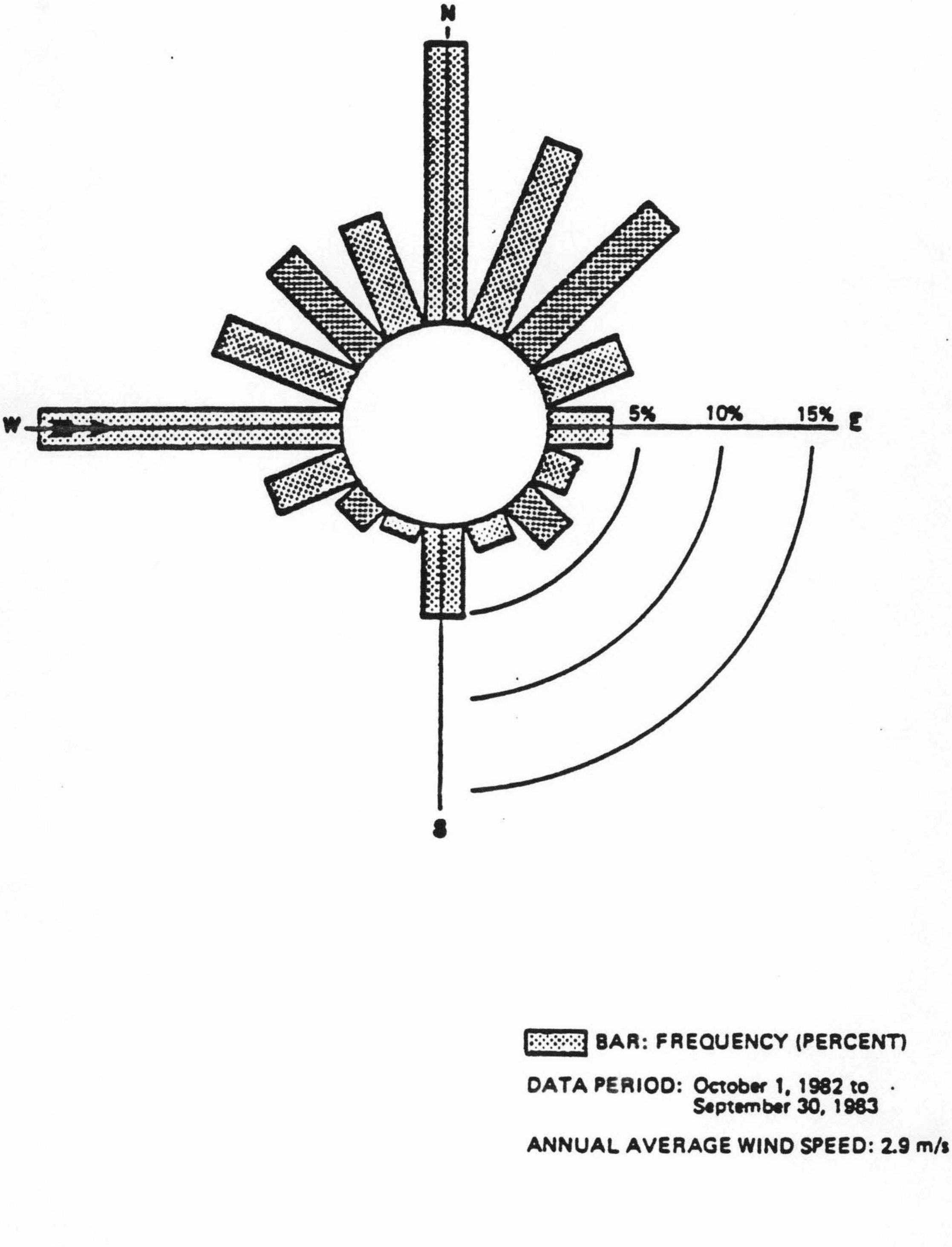


Figure IV-7

ANNUAL WIND ROSE FOR THE WOODS SITE, OCTOBER 1982 THROUGH SEPTEMBER 1983

SOURCE: DAMES & MOORE, 1984.

Table 4.4 MONTHLY AVERAGE MIXING HEIGHTS
HILO, HAWAII

Month	Morning Height (m)	Afternoon Height (m)
January	883	1,342
February	979	909
March	1,039	1,664
April	1,156	1,662
May	1,379	1,844
June	1,555	1,999
July	1,455	1,903
August	1,398	1,795
September	1,437	1,880
October	1,456	1,795
November	1,221	1,570
December	1,199	1,456
Annual	1,263	1,652

Data Period: January through December 1979
Upper Air Data Source: Hilo, Hawaii (Station No. 21504)
Surface Data Source: Barbers Point, Hawaii (Station No. 22514)

Source: Dames & Moore, 1984

Table 4.5 STATE OF HAWAII AMBIENT AIR QUALITY STANDARDS AND INCREMENTS

Pollutant	Averaging Time	Air Quality Standard (ug/m^3)
Carbon Monoxide	1-hour	10,000
	8-hour	5,000
Nitrogen Dioxide	Annual	70
Suspended Particulate Matter	24-hour	60
	Annual	150
Sulfur Dioxide	3-hour	1,300
	24-hour	365
	Annual	80
Ozone	1-hour	100
Hydrogen Sulfide[a]	1-hour	139
Hydrogen Sulfide[b]	1-hour	35

[a] Proposed ambient air quality standard.
[b] The 1-hour H_2S increment applies only to impacts resulting from geothermal power plants under normal operating conditions

quarters may not be exceeded. Standards for one-hour, three-hour, eight-hour, and twenty-four-hour periods may not be exceeded more than once in any twelve-month period.

The State of Hawaii has also proposed a one-hour hydrogen sulfide (H_2S) standard of 139 micrograms per cubic meter (ug/m^3) which may not be exceeded under any circumstance. A one-hour hydrogen sulfide increment of 35 ug/m^3 has also been proposed which applies only to geothermal power plants. This increment is the maximum allowable increase of hydrogen sulfide above natural background levels and considers all stationary sources, except for geothermal wells during testing and routine maintenance. This increment may be exceeded once during a twelve month period at any one location.

H_2S has been continuously monitored at several sites in the vicinity of the HGP-A well site (Figure IV-3). These sites include:

- Schroeder Site - located approximately 2 km south-southwest of the HGP-A site. H_2S data collection began in March 1981, and was the first site to be established.

- Hess Site - located approximately 2 km southwest of the HGP-A well site. This station began operation in July 1982.

- Gilman Site - located approximately 1 km west of the HGP-A well site. This station also began operation in July 1982.

- Wood Site - located approximately 2.5 km north of the HGP-A well site. This station began operation in April 1981.

H_2S concentrations for these sites are summarized in Table 4.6. These data show that the maximum 1-hour H_2S in this region was 68 ug/m^3 at the Schroeder site and was used in the air quality impact analysis as the worst-case ambient background concentration. These maximum concentrations are all well below the proposed state standard of 139 ug/m^3. H_2S has also been monitored at numerous locations for short periods of time. H_2S concentrations were generally found to be lower than the worst-case values reported from the above stations. Therefore, data from these sites will not be presented but a discussion of these sites can be found in NEA, Inc. (1985).

Suspended particulate matter concentrations have also been monitored in the area. Data has been collected on a long-term basis at the Bishop Estates (Upper Leilani) Leasehold

Table 4.6 ONE-HOUR AVERAGE HYDROGEN SULFIDE CONCENTRATIONS PUNA GEOTHERMAL DEVELOPMENT ZONE

	Maximum Concentration (ppmv)[a,b]					
Site	1981	1982	1983	1984	1985	1986
Schroeder	0.045	0.048	0.007	---	---	---
Gilman	---	0.016	0.008	---	---	---
Hess	---	0.014	0.008	---	---	---
Woods	0.013	0.007	0.004	0.013	0.009	0.015
Yearly Maximum	0.045	0.048	0.007	0.013	0.009	0.019

a = ug/m^3 = ppmv * (Molecular Weight/24.04) * 1000 (ug/mg)
b = Molecular Weight of H_2S = 34.08

Source: Dames & Moore, 1984; Fluor Technology, Inc., 1987 (approximately 4 km southwest of the HGP-A site), and at the visitors center of Hawaii Volcanoes National Park (located approximately 20 km east of the HGP-A well site). The U.S. EPA recently established an ambient air quality standard for inhalable particulate matter less than 10 microns (PM_{10}) of 150 ug/m^3 and 50 ug/m^3 for 24-hour and annual averaging periods, respectively. Data from the Upper Leilani site show that the maximum 24-hour PM_{10} concentration measured was 19.0 ug/m^3 on August 11, 1984. The maximum arithmetic mean for the site was 9.5 ug/m^3 during 1984. Data from the Volcanoes National Park site show that the maximum 24-hour PM_{10} concentration measured was 17.8 ug/m^3 on 23 July 1984. The maximum arithmetic mean for the site was 5.2 ug/m^3 during 1984. The maximum PM_{10} concentrations of 19.0 and 9.5 ug/m^3 was be used for the air quality impact analysis for 24-hour and annual average periods, respectively.

3.0 Air Quality Modeling and Analysis

The impact analysis in this section was excerpted from "Puna Geothermal Zone Development Cumulative Air Quality Impact Analysis" (Dames & Moore, 1989). The purpose of the report was to provide information regarding potential ambient air quality impacts related to development of 500 MW of geothermal power in the three GRS in Puna (Figure IV-8). Based on emission control data, an air quality impact assessment was prepared to estimate the potential ambient air quality impacts resulting from power plant operations.

The primary pollutant that would be emitted from the geothermal power plants is hydrogen sulfide (H_2S). H_2S is present in the geothermal stream and is released to the atmosphere during venting and/or condensing of geothermal steam. Condensing the geothermal steam results in a condensate stream and a stream of gases which do not condense (noncondensables). The H_2S in the geothermal steam can be present in both the condensate and the noncondensable streams. The analysis that follows includes data regarding emissions control and potential air quality impacts from both streams.

H_2S can also be emitted from steam vented from geothermal well drilling, well testing, and during equipment malfunctions. The data and analyses include emissions during normal geothermal power plant operation and during equipment malfunctions when a backup control system is in operation. An analysis of emissions during total regional (all geothermal plants) systems failure (steam bypass to rock muffler prior to well shut-in) is included to assess absolute worst-case impacts.

Emission estimates were based on data from wells on the Puna Geothermal Venture site (KS-1, KS-1A, and KS-2) and the HGP-A well (Fluor Technology, Inc., 1987).

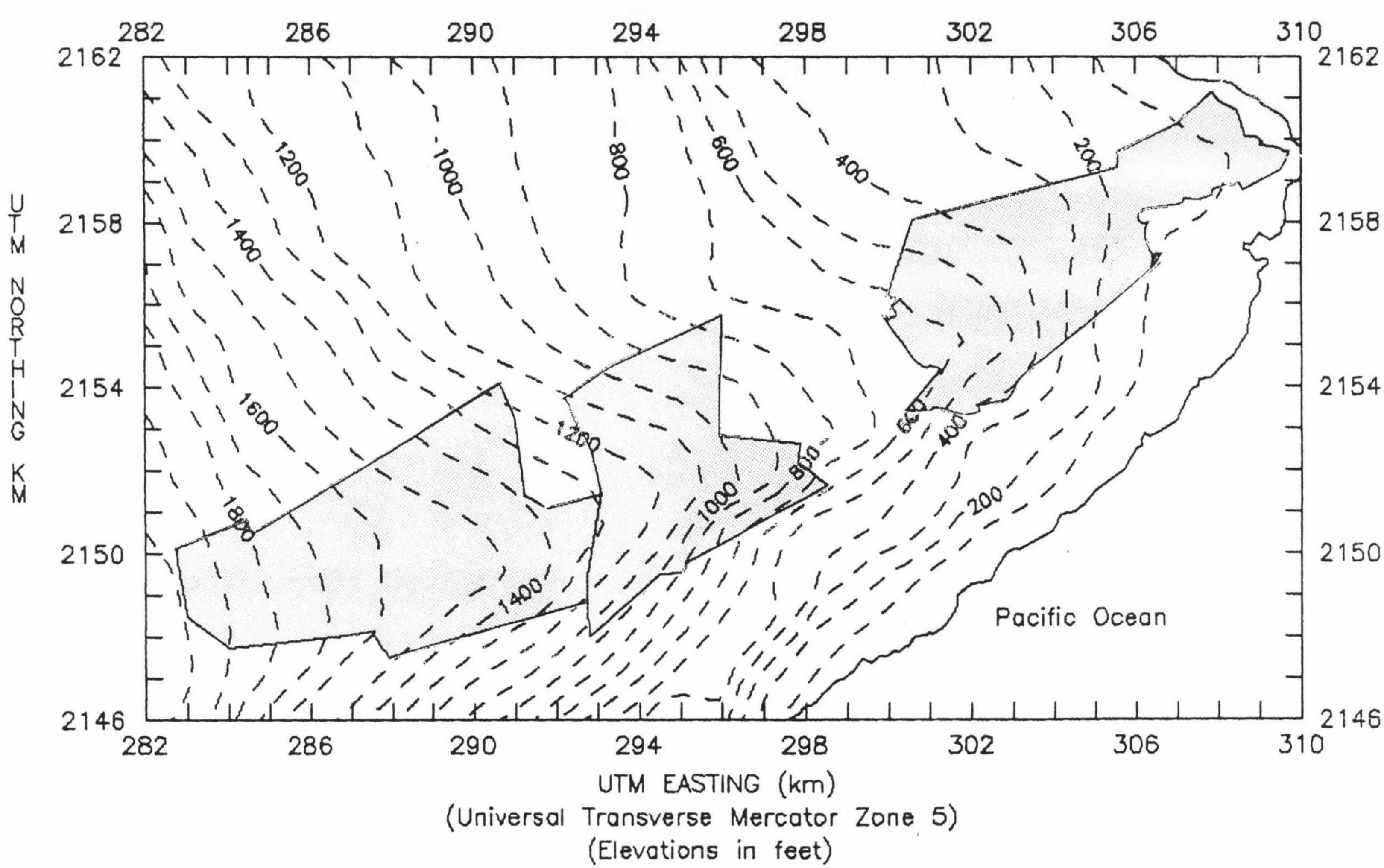


Figure IV-8
PUNA GEOTHERMAL REGION

Ambient air quality impacts resulting from the potential development of 500 net MW of geothermal-generated electricity in the Puna region were assessed. The geothermal power plant development scenario that was modeled consisted of a configuration of twelve 50 MW (gross) geothermal units in production mode. (Note: Geothermal units of different capacities would produce emissions proportionally greater or lesser depending on the size, for example, a 55 MW (gross) plant would produce 10 percent greater emissions). All modeling included emissions from the PGV project and used scaled emission rates in order to assess various pollutants plus different control strategies and control efficiencies.

Best Available Control Technology

A Hawaii Department of Health proposed air quality rule defines Best Available Control Technology (BACT) as:

> "an emissions limitation based upon the maximum degree of reduction for a pollutant which would be emitted from any proposed stationary source or modification which the director on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for that source or modification through application of production, processes or available methods, systems and techniques for control of each such pollutant. In no event shall BACT result in emissions which would exceed the emissions allowed by applicable Standards of Performance for New Stationary Sources and National Emission Standards for Hazardous Air Pollutants."

The proposed rule also specifies that the BACT shall not cause H_2S emissions to exceed the greater of 8.5 lbs./hr or 0.33 lbs./gross megawatt hour. This regulation, as applied to potential emissions from a hypothetical 50 MW geothermal power plant, would limit H_2S emissions to 16.5 lbs./hr (2.08 g/sec) or the calculated maximum allowable ground level concentration of 35 ug/m^3, whichever is less. The maximum H_2S impact of 35 ug/m^3 applies to the maximum off-site impact resulting from power plant emissions. This concentration may be exceeded once per year. Therefore, the second highest impact would be compared with the proposed increment.

The steam condensate stream from the main condenser, which contains less than one percent (0.4%) H_2S, would be directed to the cooling tower (Fluor Technology, Inc., 1987). Under all control technologies, this small H_2S fraction would have the potential to account for an emission rate of 4.7 lbs./hr (0.59 g/sec) from the cooling tower (assuming a worst-case steam H_2S content of 1300 ppm(w)) plus the remaining emissions from the noncondensable gas stream. Much of the H_2S would be oxidized by dissolved oxygen in the cooling tower makeup water under normal operating conditions to produce sulfites, reducing the actual H_2S emissions. For this assessment, a conservative assumption was made that no oxidation of H_2S would occur.

Thermal Power Company examined seven alternative control technologies to treat noncondensable vapor phase H_2S (Fluor Technology, Inc., 1987) which were:

- o Burner/Scrubber system
- o Stretford Process
- o LO-CAT Process
- o Claus-SCOT Process (with tail gas treating)
- o Selectox/CI
- o Clinsulf Process
- o Reinjection system

Each of the control technologies listed above are capable of reducing H_2S emissions below the levels specified in the proposed Hawaii Department of Health rule for BACT and emission limits.

Thermal Power Company used five criteria to evaluate the alternative control technologies (Fluor Technology, Inc., 1987) which were:

- o Emission limitations
- o Estimated capital and operating costs
- o Disposal of by-products and wastes
- o Chemical makeup requirements
- o Expected reliability and availability

Thermal Power Company also used the following assumptions in evaluating the alternative H_2S abatement technologies:

- o Power production is 30 MW (gross), although emissions in this assessment are based on 50 MW (gross).

- o 18,000 lbs./hr/MW of geothermal steam travels to the turbines.

- o All fluids are reinjected back into the geothermal reservoir.

- o The revenues from selling or costs for disposing of any sulfur product are not considered.

- o The concentration of all noncondensable gases in the geothermal steam is 3,500 ppm(w) before abatement.

- o Noncondensable gas composition as given in Table 4.7.
- o The calculated partitioning in the condenser is based on a pressure of 3 inches mercury absolute.
- o The quantity of cooling tower blowdown is 118,000 lbs./hr.

Based on the above assumptions, each of the alternative control technologies are briefly summarized in the following sections, based on data presented in Fluor Technology, Inc. (1987). Additional descriptions of the control technologies are presented in Part II of this report.

<u>Burner/Scrubber System</u>. Resulting emission rates for a hypothetical 50 MW geothermal power plant would be 4.9 lbs./hr (0.62 g/sec) of H_2S (including the condensable H_2S stream) and 2.5 lbs./hr (0.31 g/sec) of SO_2. Capital costs are approximately $1,509,600 and annual operating costs of the process are $7,187,000. Emission control costs amount to $1,664 per short ton ($1,834 per metric ton) of H_2S removed. (Note: The Dow Chemical RT-2 abatement process, a type of burner/scrubber system which is in use at the Puna HGP-A plant, also is reported to have low capital cost but relatively high operating cost).

<u>Stretford Process</u>. Resulting emission rates for a hypothetical 50 MW geothermal power plant would be 5.7 lbs./hr (0.72 g/sec). Capital costs for the Stretford unit are $7,198,200 with annual operating costs of $5,527,000 per year. Emission control costs amount to $1,280 per short ton ($1,411 per metric ton) of H_2S removed.

<u>LO-CAT Process</u>. Resulting emission rates for a hypothetical 50 MW geothermal power plant would be 5.1 lbs./hr (0.65 g/sec). Capital costs for the LO-CAT unit are $3,483,900 with annual operating costs of $948,000 per year. Emission control costs amount to $381 per short ton ($420 per metric ton) of H_2S removed.

<u>Claus-SCOT Process</u>. The Claus-SCOT process achieves a noncondensable vapor phase H_2S emission control efficiency of 100 percent, although 0.54 percent of the pre-control H_2S is emitted to the atmosphere as SO_2. The resulting SO_2 emission rate for a hypothetical 50 MW geothermal power plant would be 6.3 lbs./hr (0.79 g/sec). Furthermore, 4.7 lbs./hr (0.59 g/sec) of H_2S would still be emitted from the cooling tower based on the 0.4 percent condensable gas stream. Capital costs for the Claus-SCOT

Table 4.7 NONCONDENSABLE GAS COMPOSITION[a]

Gas	Molecular Weight	Rate (lb/hr)	Composition (Mol %)	Concentration ppm (w)
CO_2	44.01	514.30	20.55	956
H_2S	34.08	1,049.10	54.13	1950
NH_3	17.03	0.08	0.008	0.1
N_2	28.01	313.10	19.65	582
H_2	2.02	6.50	5.66	12
Total		1,883.08	100.00	3500

[a] Fluor Technology, Inc. (1987)

process are $4,702,700 with annual operating costs of $485,600 per year. Emission control costs amount to $330 per short ton ($364 per metric ton) of H_2S removed.

Selectox/Cl. Process. The Selectox/CI process achieves an H_2S emission control efficiency of 100 percent, although 0.2 percent of the pre-control H_2S is emitted to the atmosphere as SO_2. The resulting SO_2 emission rate for a hypothetical 50 MW geothermal power plant would be 2.3 lbs./hr (0.29 g/sec). Also, 4.7 lbs./hr (0.59 g/sec) of H_2S would still be emitted from the cooling tower based on the 0.4 percent condensable gas stream. Capital costs for the Selectox/CI process are $5,344,000 with annual operating costs of $748,000 per year. Emission control costs amount to $420 per short ton ($463 per metric ton) of H_2S removed.

Clinsulf Process. The resulting SO_2 emission rate for a hypothetical 50 MW geothermal power plant would be 9.4 lbs./hr (1.19 g/sec). Capital costs for the Clinsulf process are $3,282,000 with annual operating costs of $241,800 per year. Emission control costs amount to $208 per short ton ($229 per metric ton) of H_2S removed.

Reinjection. Reinjection results in only trace emissions of H_2S, with a noncondensable vapor phase control efficiency 99.96 percent resulting in a H_2S emission rate for a hypothetical 50 MW geothermal power plant of 5.1 lbs./hr (0.65 g/sec). Capital costs for the reinjection system are $4,212,600 with annual operating costs of $183,400 per year. Emission control costs amount to $238 per short ton ($262 per metric ton) of H_2S removed.

Based on the information in the preceding subsections, it appears that several emission control technologies would be acceptable as BACT. Based on the criteria used by Thermal Power Company to evaluate these control technologies, BACT for primary H_2S abatement appears to be Reinjection. Although the results of modeling indicate that Reinjection appears to represent BACT based on the above criteria, the technology has not been proven as yet and potential environmental impacts of the process itself would need to be evaluated before such an emission control system could be implemented.

Emission Scenarios

Pollutant emissions associated with geothermal development result from well drilling and power plant operation. Additional pollutant emissions occur with well testing and steam stacking during power plant malfunctions. Emissions and potential air quality impacts resulting from power plant operation were the primary focus of this analysis. An analysis of emissions during upset conditions was also included to assess absolute worst-case impacts.

Emissions from potential 50 MW geothermal power plants were based on the geothermal fluids in the Puna Geothermal Region. Geothermal fluids have been characterized for four wells in the region, three from the Puna Geothermal Venture (PGV) site (KS-1, KS-1A, and KS-2), and one at the HGP-A well. Composite data for geothermal fluid chemical composition and noncondensable gas composition from these wells are presented in Tables 4.1 and 4.2, respectively. A worst-case observed H_2S steam concentration of 1300 ppm(w) was used in all emission calculations.

H_2S emissions from geothermal development are a function of the conversion technology, H_2S content of the steam, and emission control technology. Several emission scenarios were developed to assess air quality impacts due to a wide range of emission control strategies and proposed State of Hawaii emission limitations. Emission rates for each of the control technologies are presented in Table 4.8. Each of the emission scenarios that were modeled are discussed below. To facilitate the analysis of all potential emission control strategies, the dispersion modeling was conducted using a scaled emission rate. The modeled impacts are in units of us/m^3 (microseconds per cubic meter). The actual impact is the product of the modeled impact in us/m^3 and the emission rate in g/sec, therefore, virtually any emission scenario can be assessed. All modeling scenarios also include emissions from the Puna Geothermal Venture Project (30 MW gross).

Best Available Control Technology Scenario. Given the limitations of the Reinjection system discussed in Section 2.0, the best available proven control technology for H_2S abatement appears to be the Burner/Scrubber system based on a high H_2S control efficiency (99.98 percent for H_2S and 0.21 percent for conversion to SO_2) and low initial capital costs. The Burner/Scrubber system, however, also produces a significant amount of Sulfur Dioxide (SO_2) emissions and is relatively costly to operate. Based on the assumptions presented in Sections 2.0, the H_2S emission rate using this control technology would be 0.5 lbs./hr (0.06 g/sec) from control of the noncondensable gas stream plus 4.7 lbs./hr (0.59 g/sec) from the diversion of the steam condensate stream from the main condenser to the cooling tower for a total H_2S emission rate of 5.1 lbs./hr (0.65 g/sec).

Reinjection Scenario. As stated previously, Reinjection appears to represent BACT however, the technology has not been proven as yet.

Table 4.8 ESTIMATED EMISSION RATES

Emission Control Scenario	Controlled Emission Rates H_2S (g/sec)	SO_2 (g/sec)	PM_{10} (g/sec)
Burner/Scrubber	0.62	0.31	0.01
Stretford Process	0.72	--	0.01
LO-CAT Process	0.65	--	0.01
Claus-SCOT Process	0.59	0.79	0.01
Selectox/CI	0.59	0.29	0.01
Clinsulf Process	0.59	1.19	0.01
Reinjection System	0.65	--	0.01
Proposed Hawaii H_2S Emission Limit	2.08	--	0.01
Plant Upset (rock muffler)	2.95	--	--

Based on the assumptions presented in Section 2.0, the H_2S emission rate using reinjection would be 4.7 lbs./hr (0.59 g/sec) from control of the noncondensable gas stream plus 0.5 lbs./hr (0.06 g/sec) from the diversion of the steam condensate stream from the main condenser to the cooling tower for a total H_2S emission rate of 5.1 lbs./hr (0.65 g/sec). This emission rate is based on H_2S partitioning between the vapor phase (99.6 percent) and liquid phase (0.4 percent) and a Reinjection control efficiency of 99.96 percent (Fluor Technology, Inc., 1987).

Proposed State of Hawaii Emission Limitations Scenario. Emission limitations proposed by the State of Hawaii would limit the emission of H_2S to the greater of 8.5 lbs./hr (1.07 g/sec) or 150 grams (0.33 pounds) per megawatt hour. Based on this proposed limitation, the maximum H_2S emission rate from a 50 MW geothermal power plant would be 16.5 lbs./hr (2.08 g/sec). This emission scenario was included to assess potential worst-case air quality impacts under the assumption that geothermal units were all emitting the maximum amount of H_2S that would be allowed by the proposed rule which is unlikely.

Other Control Technologies. Emission rates were calculated for all of the H_2S emission control technologies discussed previously in this analysis and were presented in Table 4.8. Since the model output represents impacts based on a unit emission rate, all emission control technologies can be assessed by multiplying the emission rate times the modeled concentration.

Power Plant Upset Condition H_2S Emissions. H_2S emissions during power plant upset conditions were also modeled to estimate absolute worst-case emissions. Steam venting or "stacking" is the release of steam to the atmosphere during a plant outage, with the outage caused by scheduled maintenance, system failure, or complete loss of electrical power supply to the plant.

To avoid excessive emissions during steam stacking, well throttling and shut-in would be required in conjunction with a rock muffler/chemical injection system. With automatic controls, the wellhead throttling valve responds automatically to a rise in line pressure (corresponding to a turbine trip) by closing. The well can be closed completely in 20 seconds to 30 minutes even in the event of a complete loss of electrical power supply (Acurex, 1980).

During the period prior to well shut-in, a rock muffler/ chemical injection system could be used to control H_2S emissions. Based on a state-of-the-art rock muffler design (Gibbs & Hill, 1982; Dames & Moore, 1984) H_2S emissions can be reduced by 98 percent during upset conditions.

A worst-case upset condition scenario was modeled to estimate the worst possible release of H_2S emissions to the atmosphere and resulting exposure to the surrounding population. Assuming a rock muffler control efficiency of 98 percent, a steam H_2S concentration of 1300 ppm(w), and a steam flow rate of 900,000 lbs./hr per geothermal plant, emissions from each power plant would be 23.4 lbs./hr (2.95 g/sec). This worst-case emission scenario assumed simultaneous upset conditions for all production wells at each power plant which is highly unlikely.

Particulate Matter Emissions. Emissions of particulate matter were assumed to be the same under each of the above emission scenarios. Particulate matter emissions were based solely on the total dissolved solids (TDS) content of the cooling tower makeup water. The following assumptions, from the emission calculations for the Puna Geothermal Venture Project (Fluor Technology, Inc., 1987), were used to calculate particulate matter emissions from the cooling tower:

- Steam condensate used for cooling tower makeup water
- Circulating water flow = 51,000 gpm
- Cooling tower drift = 0.005 percent
- Number of cycles = 5
- TDS = 15 ppm(w)
- All particles have an aerodynamic diameter of 10 microns or smaller (PM_{10})

The resulting emission rate using the assumptions given above was 0.1 lbs./hr (0.01 g/sec). The cooling tower water quality, in terms of TDS, would obviously have a significant impact on the particulate matter emission rate. If the cooling tower makeup water TDS content were significantly different, the particulate matter emission rate would vary by a factor of five based on the number of cycles. Since all modeling used a scaled emission rate, particulate matter emission rates which vary significantly from the emission rate presented above could also be assessed.

Air Quality Modeling

The purpose of the air quality impact analysis (AQIA) is to estimate pollutant concentrations from the potential geothermal power plants and to assess the significance of the impacts in regards to applicable ambient air quality standards and increments. Computer based dispersion modeling techniques were applied to simulate the release of pollutants from the hypothetical sources. The pollutants considered in the analysis included hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and particulate matter less than 10 microns (PM_{10}). The methodologies that were employed in the analysis, including the emission scenarios assessed, a description of the dispersion modeling techniques, and required model input data, are discussed below.

Modeling Scenario. A modeling scenario was developed to assess cumulative air quality impacts of emissions from geothermal power generation. The scenario modeled basically consisted of a configuration of twelve 50 MW geothermal units in production mode. Each unit was spaced so that the distance between units is at least one kilometer in each of the three geothermal zones. Also, 200 MW of power would be produced in each geothermal subzone. The scenario that was modeled is presented in Figure IV-9.

All modeling used scaled emission rates in the actual modeling runs. The model output yields values of X/Q in units of us/m^3 (microseconds per cubic meter) which is the dimensionless concentration as a function of emission rate. "X" represents the atmospheric concentration in ug/m^3 while "Q" represents the emission rate in g/sec. The actual atmospheric concentration can be calculated by multiplying the X/Q impact in us/m^3 by the actual emission rate in grams per second (g/sec). Therefore, all control technologies and emission scenarios could be examined.

Description of Dispersion Models. The initial proposal was to model the proposed development scenario using meteorological data from the Woods Residence monitoring station and the following models:

- ISCST (level or sloping terrain)
- MPTER (sloping terrain)
- COMPLEX-I (complex terrain)

After reviewing the terrain in the Puna Geothermal region, in was determined that elevation variations were too large to apply the MPTER model since it is only valid in the range between stack base and stack top elevations. The

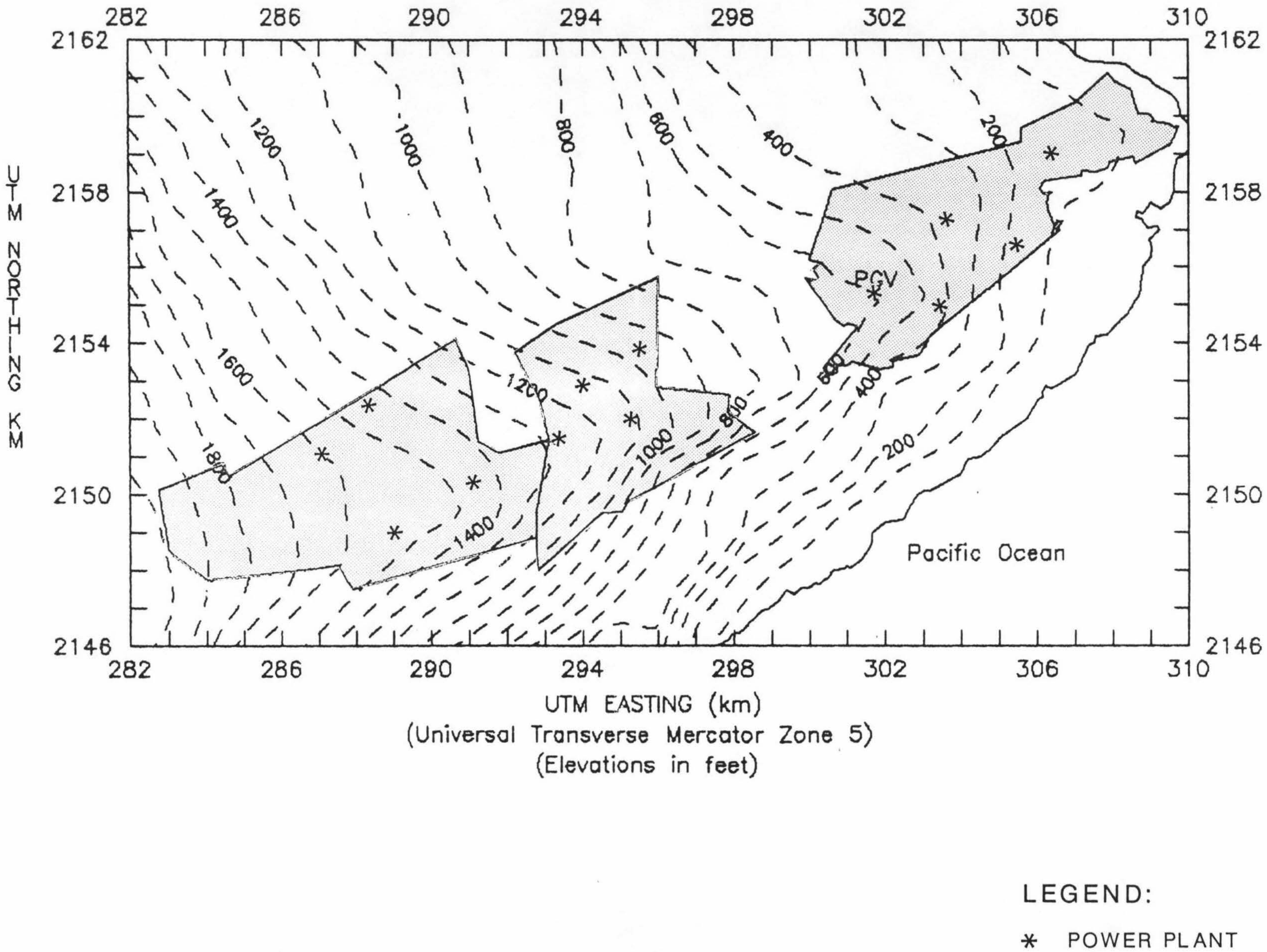


Figure IV-9

PUNA GEOTHERMAL REGION DEVELOPMENT SCENARIO

MPTER model does not calculate concentrations for any receptor outside of this elevation range. For the modeling scenario presented above, the range of elevations were greater than allowed by the MPTER model, and therefore, the model was not applied. The ISCST and COMPLEX-I models were applied to simulate simple and complex terrain features, respectively.

The ISCST (Industrial Source Complex Short Term; UNAMAP version 6) model was designed for modeling complex source configurations (point, volume, and area) in areas with relatively flat terrain. Building wake algorithms are included to simulate the enhanced dispersion induced by the structures around the sources considered. Gravitational settling and deposition routines are also included within ISCST, but were not applied in the present study. Apart from the building wake algorithms, the flexibility to simulate volume and area sources, and particulate deposition, ISCST is based on the same Gaussian structure and employs the same dispersion curves and plume rise prediction techniques as are found in the MPTER and COMPLEX-I models.

The COMPLEX-I (UNAMAP version 6) model has been designated by the U.S. Environmental Protection Agency (U.S. EPA) as the preferred screening method for assessing the impacts of sources on elevated terrain. In the present context, elevated terrain refers to receptor locations above the elevation of the lowest stack to be considered in the modeling analysis. The dispersion assumptions in this model are based primarily on the EPA- developed VALLEY model (Burt, 1977). Plume height in COMPLEX-I is adjusted by the near-impingement method during stable conditions and the half-height method during neutral or stable conditions. As in the VALLEY model, horizontal dispersion during stable periods empirically includes the effects of terrain using a sector width approximation.

The regulatory default option was exercised for both the ISCST and COMPLEX-I models for the selection of model options pertaining to the treatment of complex terrain, wind profile coefficients, buoyancy induced dispersion, plume rise, and calm wind processing. Using these techniques, the highest and second highest concentrations for each scenario were estimated.

Model Input Data. Required input data for the ISCST and COMPLEX-I models include receptor locations and elevations, pollutant emission rates and stack characteristics for each source, and hourly meteorological data for a period of up to one year. These input data requirements are summarized below.

Meteorological Data

Meteorological data required for modeling were extracted from observations taken at the Woods Residence monitoring station. The Woods Residence data were selected for the modeling study because measurements of standard deviation of wind direction (sigma-theta) were available at this site which allowed the calculation of atmospheric stability.

Data recorded at the Woods Residence site from February 1982 through January 1983 were available as hourly averages for every third hour (local standard time hours (0000, 0300, 0600, etc.). The remaining data for February 1983 through September 1983 were complete in that hourly averages were recorded for each hour. The most complete year of meteorological data available for modeling was October 1982 through September 1983. During periods when observations were recorded only every third hour, missing data were linearly interpolated.

The meteorological data were processed prior to input into the dispersion models. Wind direction, recorded to the nearest 5 degrees, was randomized to within $+2^{o}$ to -2^{o} of the recorded wind direction by a random number generator and then converted to a flow vector. Pasquill-Gifford stability class was calculated from sigma-theta as described by the U.S. EPA (1986). During the nighttime (one hour prior to sunset to one hour after sunrise), adjustments to sigma-theta defined stability class based on wind speed were performed (U.S. EPA, 1986). Sigma-theta values were not adjusted for surface roughness. A mixing height of 300 meters was assumed based on observed worst-case conditions in the area (Dames & Moore, 1984). However, maximum modeled concentrations were not affected by mixing height because maximum concentrations were projected to occur during stable atmospheric conditions when mixing height does not affect plume dispersion.

Receptor Data

The receptor grid was defined in cartesian coordinates over the entire Puna Geothermal region utilizing 500 meter grid spacing and was designed to assess cumulative scenario impacts. Site specific terrain features, such as volcanic craters, were also considered to assess site specific impacts from the proposed development scenario. Sub-receptor grids were defined based on the specific terrain features near some of the proposed development locations. Figure IV-10 shows the

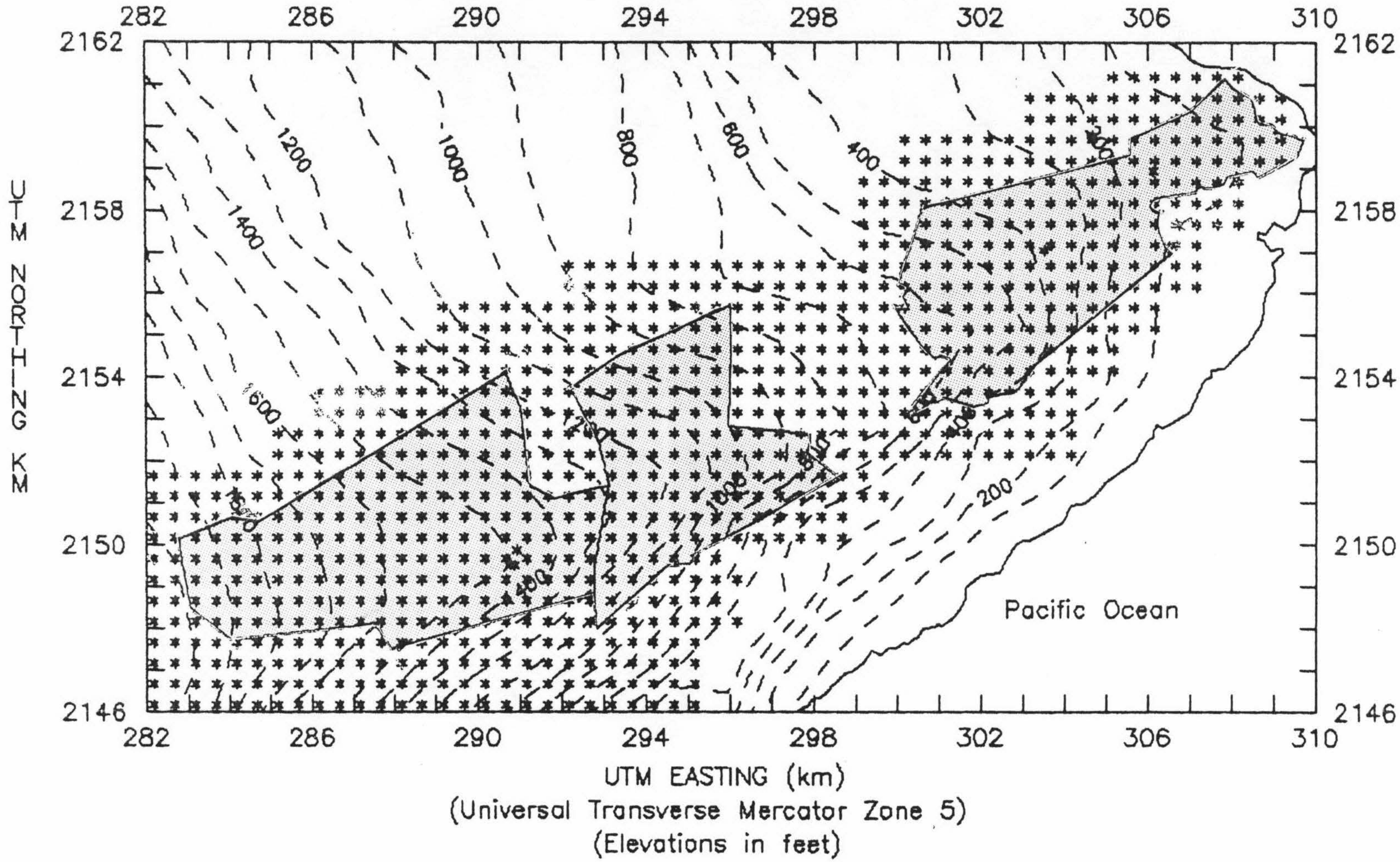


Figure IV-10
PUNA GEOTHERMAL REGION RECEPTOR GRID

distribution of receptors across the Puna Geothermal region.

Emission Source Data

Pollutant emissions associated with geothermal well development result from well drilling and power plant operation. Additional pollutant emissions occur with well testing and steam stacking during power plant malfunctions. Potential air quality impacts mainly resulting from power plant operation were considered in this analysis as they relate to the proposed State of Hawaii standards and increments. Upset condition emissions were also modeled as an indication of maximum project impacts and population exposure.

Operation stack parameters were based on typical cooling tower parameters from similar sized projects and are presented in Table 4.9. To test the sensitivity of the dispersion models, stack heights equal to 50 and 200 percent of the original stack height were also modeled for the Reinjection scenario. Rock muffler stack parameters were based on data from the HGP-A and Geysers projects.

4.0 Air Quality Impacts

Modeling results of the proposed 600 MW development scenario yielded acceptable results for all applicable pollutants and standards. Potential PM_{10}, SO_2, and H_2S impacts are summarized below.

Fine Particulate Matter (PM_{10})

Modeling results of the proposed development scenario show PM_{10} impacts well below the federal 24-hour and annual average PM_{10} standards of 150 and 50 ug/m^3, respectively, as shown in Table 4.10. It should be noted, however, that the particulate matter emission rate was based on a cooling tower water total dissolved solids (TDS) concentration of 15 ppm(w) (Fluor Technology, Inc., 1987). The modeled PM_{10} impact would vary proportionally to any changes in the cooling tower water TDS concentration.

Also several assumptions were made regarding the characteristics of the particulate matter. First, all particulate matter was assumed to have a diameter of less than 10 microns. Second, no water droplet deposition was considered in the modeling. In reality, large water droplets in the cooling tower drift settle to the ground within a few hundred feet of the cooling tower. The effect of this is to deplete cooling tower plume concentrations over a relatively short distance and reduce cumulative impacts. All modeling results

Table 4.9 STACK PARAMETERS

Parameter	Cooling Tower	Rock Muffler
Stack Height (m)	16.8	9.8
Stack Diameter (m)	8.4	2.1
Stack Gas Temperature (^{O}K)	316	373
Stack Gas Exit Velocity (m/sec)	8.3	29.5
H_2S Emission Rate (g/sec)	Variable[a]	2.95
PM_{10} Emission Rate (g/sec)	Variable[a]	--

[a]Emission rate depends on emission control technology employed.

Source: Dames & Moore, 1984.

Table 4.10 PM_{10} MODELING RESULTS

Emission Scenario[a]	24-Hr PM_{10} Impact (ug/m^3)	24-Hour EPA PM_{10} Standard (ug/m^3)	Annual PM_{10} Impact (ug/m^3)	Annual EPA PM_{10} Standard (ug/m^3)
Burner/Scrubber	0.04	150	0.01	50
Stretford	0.04	150	0.01	50
LO-CAT	0.04	150	0.01	50
Claus-SCOT	0.04	150	0.01	50
Selectox/CI	0.04	150	0.01	50
Clinsulf	0.04	150	0.01	50
Reinjection	0.04	150	0.01	50

[a] All maximum impacts resulted from COMPLEX-I dispersion model under stable atmospheric and low wind speed conditions.

seem to indicate that PM_{10} impacts would not be a limiting factor in geothermal power plant siting unless the cooling tower makeup water was extremely poor in terms of TDS concentrations.

Sulfur Dioxide (SO_2)

Emissions of SO_2 would only occur if the Burner/Scrubber, Claus-SCOT, Selectox/CI, or Clinsulf control technologies were utilized for H_2S abatement. Next to Reinjection, the Burner/Scrubber system was identified as the best technology for H_2S abatement based on relatively low initial capital costs. Assuming a worst-case SO_2 emission rate of 9.4 lbs./hr (1.19 g/sec) (Clinsulf process) and a maximum modeled impact of 12.6 us/m^3, the maximum 3-hour SO_2 concentration would be 15.0 ug/m^3. The maximum 24-hour and annual average SO_2 concentrations would be 3.7 and 0.9 ug/m^3, respectively. These maximum impacts would compare to Hawaii Department of Health SO_2 standards of 1300, 365, and 80 ug/m^3, respectively. Maximum SO_2 concentrations do not appear to be a limiting factor in the siting of power plants in the Puna geothermal region.

Hydrogen Sulfide (H_2S)

Modeling results for the seven emission control technologies and the proposed development scenario are presented in Table 4.11 for H_2S impacts. All seven control technologies yielded acceptable impacts well below the proposed Hawaii H_2S increment of 35 ug/m^3.

Several factors need to be considered when interpreting these results. First, the emission rates were based on a worst-case observed noncondensable gas H_2S concentration of 1300 ppm(w) which is well above the minimum observed concentration of 800 ppm(w). If emissions were based on the minimum H_2S noncondensable gas concentration at the HGP-A well of 600 ppm(w) (Thomas, 1982b), or on an area weighted average noncondensable gas concentration, H_2S impacts would be considerably lower. Second, the dispersion models are very sensitive to the orientation and spacing of the individual 50 MW geothermal units in terms of the location of each unit in relation to the terrain and to other units. When individual 50 MW geothermal units were modeled separately at various locations within the Puna Geothermal zone, impacts ranged from 4.2 to 19.7 us/m^3 in areas of elevated terrain with an impact of 5.4 us/m^3 in areas of flat terrain (since all units were assumed to be identical, impacts in flat terrain are also identical).

To test model sensitivity, stack heights were varied from approximately 50 to 200 percent of the original value. Modeling results showed that the impact at the 50 percent stack height value (8.4m) was 27.4 us/m^3 or an increase of 39.1 percent.

Table 4.11 MODELED HYDROGEN SULFIDE IMPACTS

Emission Scenario	Modeled[a,b] Impact (us/m^3)	Emission Rate (g/sec)	1-Hr H_2S Impact (ug/m^3)	1-Hr H_2S Increment (ug/m^3)	Percent of Increment
Burner/Scrubber	19.69	0.62	12.2	35.0	34.9
Stretford	19.69	0.72	14.2	35.0	40.6
LO-CAT	19.69	0.65	12.8	35.0	36.6
Claus-SCOT	19.69	0.59	11.6	35.0	33.1
Selectox/CI	19.69	0.59	11.6	35.0	33.1
Clinsulf	19.69	0.59	11.6	35.0	33.1
Reinjection	19.69	0.65	12.8	35.0	36.6
Proposed Hawaii Emission limit	19.69	2.08	41.0	35.0	117.1

[a] All maximum impacts resulted from COMPLEX-I dispersion model under stable atmospheric and low wind speed conditions.
[b] Modeled impact is represented by the second highest impact since the proposed H_2S increment would allow for one exceedance per year.

Results for the 200 percent stack height value (33.6m) showed that the impact decreased to 13.6 us/m^3 or a decrease of 31.0 percent. Modeling results for the Reinjection emission scenario yielded a H_2S impact of 12.8 ug/m^3 which is well below the proposed Hawaii H_2S increment of 35 ug/m^3 (approximately 37 percent of the standard). Since the modeling analysis used several conservative assumptions regarding H_2S steam concentrations and atmospheric dispersion, development impacts would probably be lower.

Modeling results for the BACT H_2S abatement scenario, utilizing the Burner/Scrubber system, yielded similar results as the Reinjection scenario since the emission rates were similar (0.62 g/sec for the Burner/Scrubber vs. 0.65 g/sec for Reinjection). Therefore, the Burner/Scrubber system would perform well for H_2S abatement based on relative performance.

Modeling results for the proposed Hawaii H_2S emission limit scenario are presented in Table 4.11. These results show that modeled concentrations for the proposed development scenario could exceed the allowable proposed increment of 35 ug/m^3. Increasing stack height would reduce impacts significantly as shown above. Assuming an increased stack height of 33.6 meters, H_2S impacts would decrease to 28.3 ug/m^3, which is below the proposed increment of 35 ug/m^3. Modeling on a case-by-case basis for individual projects would be necessary to estimate compliance with the proposed increment.

The upset condition emissions scenario showed that the maximum H_2S impact of 90.2 ug/m^3 would be well above the proposed Hawaii Department of Health increment of 35 ug/m^3 and below the proposed standard of 139 ug/m^3, although short-term upset emission impacts are exempt from the proposed regulations. A regional upset condition is highly unlikely. While these upset emissions are not regulated by the proposed Hawaii Department of Health regulations, impacts would probably remain below the proposed standard and not constitute any health risk.

Under normal operating conditions, H_2S concentrations would also be expected to be below the odor threshold. An odor threshold of 0.01 ppmv (14.2 ug/m^3) has been identified by the American Conference of Governmental Industrial Hygienist (ACGIH) as reported by Sax (1984). Data presented in Table 3.11 indicates that worst-case H_2S impacts would remain below the odor threshold for all emission scenarios except for the Stretford Process and the State of Hawaii emission limit scenarios. Worst-case H_2S concentrations under cumulative power plant upset conditions would also exceed odor thresholds, but this scenario is highly unlikely.

Emissions related to geothermal development would not be expected to increase acid rain in the area. Natural emissions of H_2S from fissures and volcanic activity in the area range from 1,200 to 1,600 metric tons per day, according to the U.S. Geological Survey. Based on geothermal development of 500 MW of electricity, total H_2S emissions from generating plants would amount to less than one metric ton. Therefore, emissions related to geothermal power generation would have an insignificant effect on acid rain in the area.

5.0 Conclusions and Recommendations

Several significant factors are apparent after a review of available H_2S control technologies and the air quality impact analysis. Several control technologies would be capable of achieving similar noncondensable stream H_2S emission reductions in the 99.9 percent and above range. Partitioning of the geothermal steam directs 99.6 percent of the H_2S stream, as a noncondensable gas, to one of the control technologies discussed previously. The remaining 0.4 percent condensable H_2S stream would be diverted to the cooling tower basically as an uncontrolled emission. The most significant H_2S stream, in terms of total emissions, is the condensable gas stream that would be diverted directly to the cooling tower. In the case of the Reinjection scenario, emissions from the condensable gas stream make up approximately 90 percent of the total H_2S emissions. Similar partitioning is characteristic of the other emission control techniques that were examined. It should be noted that there is considerable uncertainty in estimating H_2S emissions from cooling towers. Oxidation of H_2S would occur in the cooling tower, thus reducing actual H_2S emissions. For this assessment it was conservatively assumed that no H_2S oxidation would occur. Actual H_2S emissions from a cooling tower under normal operating conditions would probably be lower.

Results of the dispersion modeling for each emission scenario showed that development of 500 MW of geothermal power in the Puna region would probably not reduce air quality below any applicable standards or increments. Each of the seven H_2S emission control technologies examined yielded acceptable impacts in relation to the proposed Hawaii H_2S increment of 35 ug/m^3. Under the worst-case normal operating condition emission scenario, the proposed Hawaii emission limit of 0.33 pounds (150 grams) per megawatt hour, impacts were only slightly greater that the proposed increment. A refined analysis on a case-by-case development proposal would probably yield acceptable impacts. Other pollutants, such as SO_2 and PM_{10}, were found to not be significant factors for siting of geothermal power plants in the Puna geothermal region. PM_{10} emissions would be a significant factor only if the cooling tower makeup water contained total dissolved solids (TDS) concentrations that greatly exceeded the concentration of 15 ppm(w) used in this analysis.

Air quality impacts resulting from power plant and production well upset conditions were also examined. Modeling results indicated that impacts could exceed the proposed H_2S increment of 35 ug/m^3 but remain below the proposed standard of 139 ug/m^3. Health risks associated with this highly unlikely upset condition would be negligible.

While the overall modeling results indicate only a very slight potential for significant H_2S air quality impacts (under the proposed State of Hawaii maximum allowable H_2S emission scenario or upset conditions), several assumptions used in the H_2S emission calculations and dispersion modeling have lead to estimated H_2S impacts which are probably much greater than would actually occur. H_2S emission calculations were based on a maximum H_2S steam concentration. Based on data from geothermal wells in the region, steam H_2S concentrations in some areas could be lower than the maximum value used in this assessment.

Under normal operating conditions, H_2S concentrations would be expected to remain below odor thresholds for most emission scenarios. Under worst-case upset conditions, H_2S concentrations would have the potential to exceed the odor threshold, but these upset conditions are highly unlikely.

Another significant factor which leads to overestimation of H_2S impacts is the inherent conservatism in the COMPLEX-I model. Maximum H_2S impacts all resulted from the COMPLEX-I modeling scenarios due to the relatively complex terrain features in the Puna Geothermal region. The U.S. EPA recently designated the COMPLEX-I model as a second level screening model for use in complex terrain. The third level screening model designated by the EPA is the Rough Terrain Diffusion Model (RTDM) which was added to the list of EPA preferred models on January 6, 1988 (51 FR 35610). RTDM is based on state-of-the-art complex terrain modeling techniques developed as part of the Complex Terrain Model Development (CTMD) Program. Model evaluation studies have shown that RTDM performs better and is less conservative then the COMPLEX-I model. If each of the above emission scenarios were remodeled using RTDM and meteorological data from the Puna Geothermal region, more refined results would be achieved. More refined (less conservative) modeling results would help to improve any decisions made with regards to geothermal power plant siting based on air quality in the Puna Geothermal region. The RTDM model was not applied in this study due to several model limitations pertaining to simulations of multiple sources. The RTDM model requires that all sources are collocated. Therefore, it would not be well suited for a multiple source simulation where sources are distributed over a large area. The RTDM model should be used in permitting of individual geothermal power plants on a case-by-case basis.

C. HYDROLOGY AND WATER QUALITY

1.0 Regional Hydrology

The island of Hawaii has abundant water resources with over 14,000 million gallons per day (mgd) of rainfall. Approximately 25 percent of this volume flows to the ocean as runoff, 31 percent infiltrates as groundwater recharge, and the balance is returned to the atmosphere as evapotranspiration (Feldman and Siegel, 1980).

With its five volcanic systems, a wide variety of hydrogeological regimes exist on the island. As is typical of the Hawaiian Islands, the greatest volume of precipitation occurs on the windward (northeast) slopes. Most of the island's surface runoff occurs on the older, more weathered volcanoes of Mauna Kea and Kohala Mountain.

The Ghyben-Herzberg lens model can generally be applied to the island of Hawaii. This model indicates that fresh water beneath ocean islands floats on seawater to a depth below sea level which is 40 times the depth above sea level. This general model requires considerable modification due to local meteorologic and geologic conditions.

Extensive dikes, resulting from volcanic activity, effectively restrict groundwater flow and trap precipitation in formations very different from the Ghyben-Herzberg basal lens (Figure IV-11). Ash deposits may form impermeable layers resulting in perched groundwater tables. Figure IV-12 outlines the general groundwater reservoirs found on the island of Hawaii.

2.0 Local Hydrology

Kilauea, the island's youngest volcano, has only minimal soil development and few interlayed ash beds allowing precipitation to percolate rapidly into the ground. There are no permanent surface streams and only one small lake, Green Lake in Kapoho Crater, which results from a localized ash layer causing a perched water table.

The East Rift Zone of Kilauea Volcano, as with other rift zones of Hawaiian volcanoes, imposes two major modifications on the Ghyben-Herzberg model. First, the extensive system of faults and dikes in the rift zone traps precipitated fresh water, resulting in its occurrence at high elevations and at greater depths than could be attributed to the basal lens. Second, the nearly vertical structure and impermeable nature of the dike and fault system of the rift zone creates a barrier to groundwater flow.

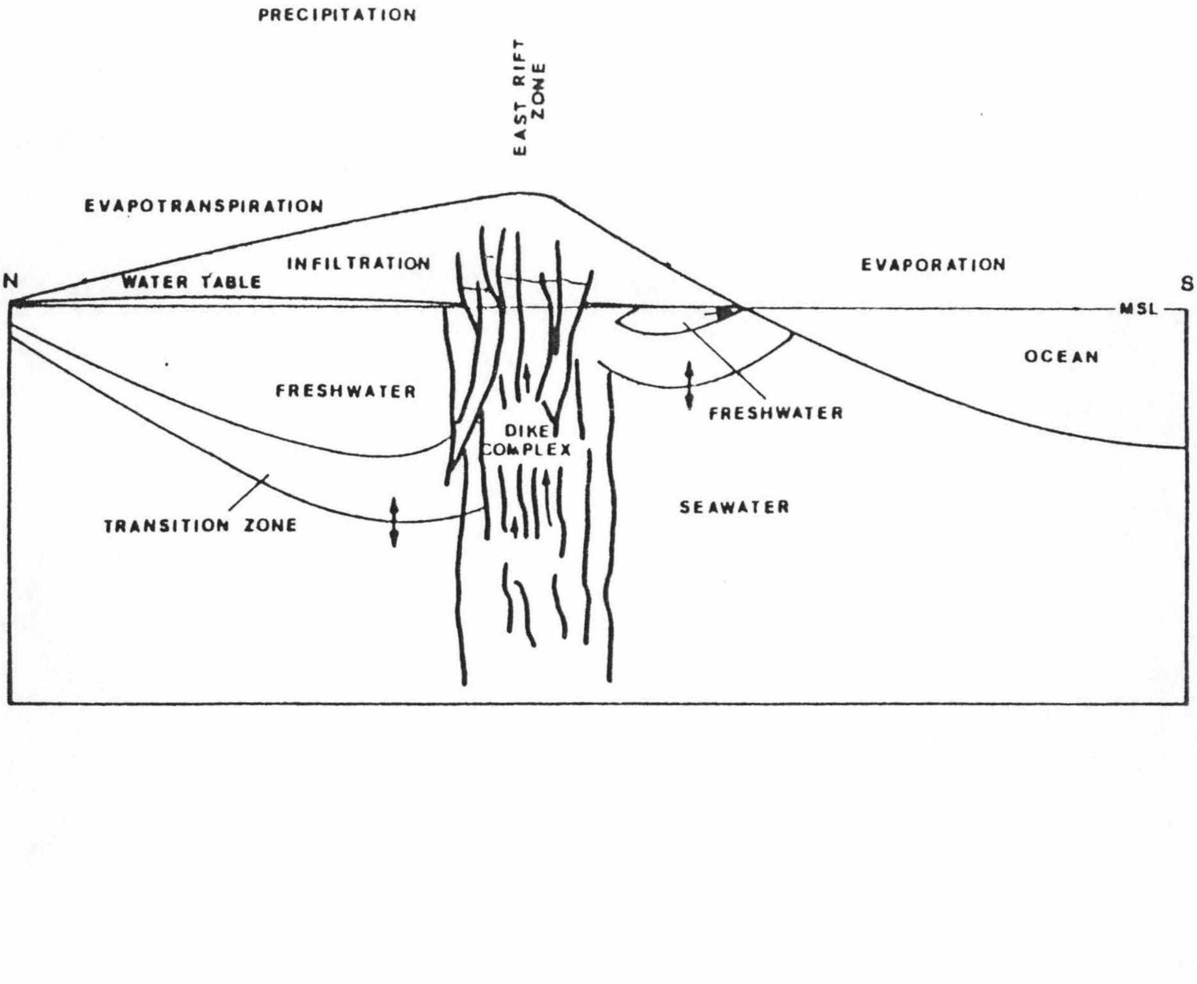
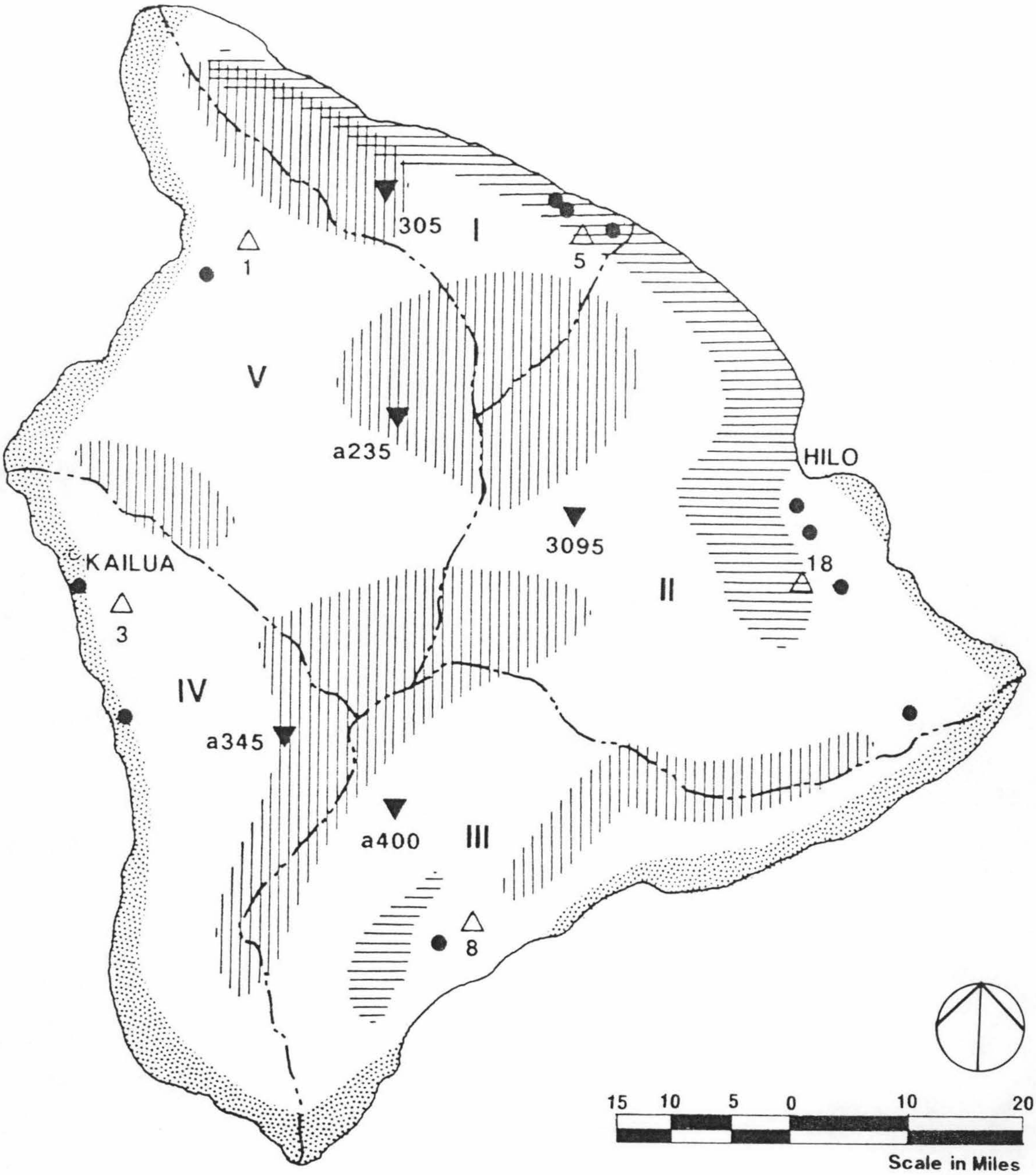


Figure IV-11

SCHEMATIC NORTH-SOUTH CROSS-SECTION THROUGH PUNA SHOWING RECHARGE, MOVEMENT, DISCHARGE, STORAGE, AND SUBSURFACE GEOLOGY OF GROUNDWATER

SOURCE: DRUECKER AND FAN, 1976.



LEGEND:

- ▼ Ground-water recharge (million gallons per day)
- △ Ground-water draft (million gallons per day)
- ● Principal supply wells
- a High recharge rate owing to high capacity of land surface to absorb rainfall.
- II Hydrographic area representing major drainage basin
- Ground water impounded by dikes
- Ground water perched on soil or ash layers overlying basal ground water
- Basal ground water floating on saline ground water
- Brackish basal ground water

Figure IV-12

GROUNDWATER RESERVOIRS

SOURCE: MODIFIED FROM FELDMAN AND SIEGEL (1980).

Precipitation in Puna averages about 100 inches per year. North of the rift, rainfall is about 140 inches annually while the southeast coast is drier with approximately 80 inches per year. Recharge loss due to evapotranspiration is estimated to be from 10 to 30 inches annually (Imada, 1984; Fluor Technology, Inc., 1987).

Hydraulic gradients along the northeast coast of Puna range between two and four feet per mile with water table elevations of 12 to 18 feet above sea level five to six miles inland. In contrast, the southeast coast which receives less precipitation and is separated by the East Rift Zone, has gradients ranging between one and two feet per mile with water table elevations of three to four feet above sea level a mile and a half inland (Druecker and Fan, 1976). Circulation within the East Rift Zone itself is probably minimal and is thought to be parallel to the rift (Fluor Technology, Inc., 1987).

Tritium concentration and oxygen isotope ratios of groundwater that recharge is primarily local and mean residence time of these ground waters does not exceed a few years (Kroopnick et al., 1978). The basal ground water is discharged along the coasts in the form of diffuse flows and a few large basal springs. Along the northeast coast, the daily groundwater discharge is estimated to be several million gallons. Along the southeast coast, this discharge is much lower (Imada, 1984).

Although permeability of the basal aquifer is high and yields greater than 300 gpm per foot of drawdown are common, discharge of groundwater through wells is low because of limited demand for the water (Imada, 1984). This limited demand is partly the result of the brackish nature of the water south of the rift zone.

3.0 Water Quality

The location of some wells in Puna is shown in Figure IV-13. Chemical data from some of these wells is provided in Table 4.12. Pahoa area wells, north of the rift zone, provide an abundance of high quality fresh water from an aquifer estimated to be over 600 feet deep in that area. Geothermal wells, drilled to depths greater than 1800 feet in the rift zone, have indicated the existence of hot (greater than 200 degrees Celsius) geothermal resources at these depths. This deep geothermal reservoir appears to be at least partially separated from the shallower ground water by layers of low permeability (Figure IV-2). South of the rift zone, ground water tends to be abnormally warm and saline. Discharge of this water to the ocean results in warm geothermal springs along a portion of the southeast coast of Puna. This suggests that warm water is escaping from deeper geothermal reservoir or dike complexes into the basal water, the warm saline rising through

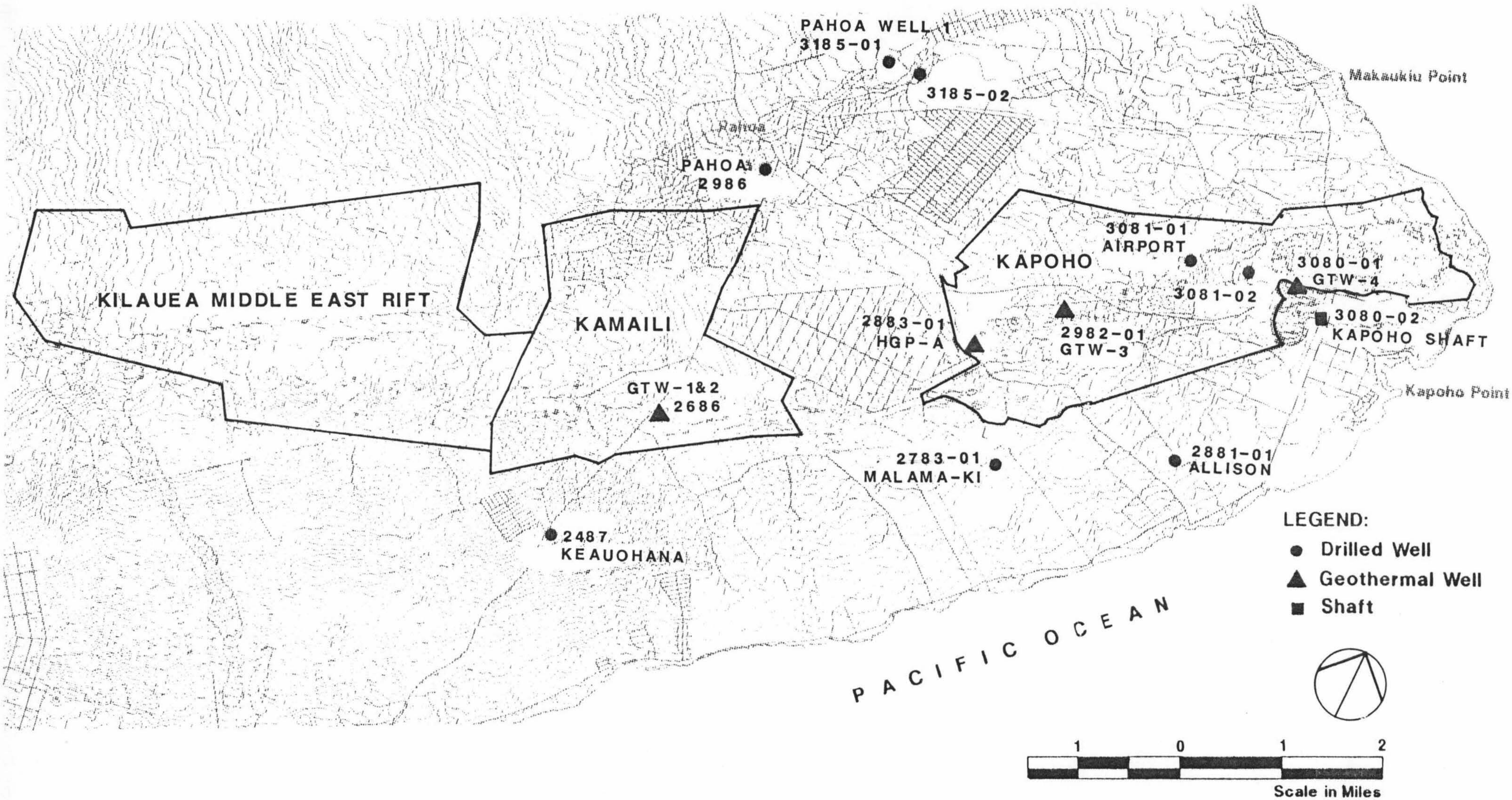


Figure IV-13

WATER WELLS IN THE PUNA AREA

Table 4.12 CHEMICAL COMPOSITION FOR PUNA AREA WELLS [a]

USGS/BWS No.	Name	Date	T (°C)	pH	Na	K	Ca	Mg	Cl	HCO_3	SO_4	SiO_2	T[(d)]
2986-01	Pahoa Station	01-06-75		7.30	36.0	2.72	1.58	2.7	13.5	48	21.1	50.0	9.9
9-5	elev. 705' pumped	07-21-75	23.3	6.65	19.3	2.7	1.6	1.9	9.8	44	27.3		10.6
2487-01	Kalapana Station	01-06-75	28.5	7.68	89.6	5.20	5.30	6.6	132.2	38	37.2	44.5	16.7
9-7	elev. 752' pumped	07-21-75	20.8	7.05	78.8	5.0	5.9	5.6	120	36.8	28.6		18.0
3080-02	Kapoho Shaft	01-06-75	25.5	7.80	85.8	6.60	42.4	37	16.9[(b)]	372	20	53.6	14.1
9	elev. 38'	07-21-75	22.1	7.10	86.5	6.2	23.2	25.7	95.7	328	22.7		10.5
		10-27-75			92.0	5.8	32.0	27.8	105	330	23.0		--
3081-01	Airstrip Well	01-06-75	36.8	7.42	238	13.6	23.0	28	303.5	48	204	71.3	--
9-6	elev. 287' depth 285'	07-22-75	33.5	7.75	223	16.8	12.5	27.2	316	44	211		11.1
2881	Allison Well elev. 140' depth 144'	01-07-75	37.8	7.35	216	10.8	13.4	15	281	132	69.2	24.1	12.9
	Isaac Hale Park	01-07-75	36.0	7.75	2020	86.0	32.4	200	3534	56	507	81.5	8.5
	Spring	10-27-75			2140	87.5	98.0[(b)]	239	3660	61.0	552		--
2783-01	Malama Ki Well	01-07-75	52.2	7.02	2105	109	66.8	210	3811	144	471	100.7	15.6
9-9	elev. 274' depth 276'	07-22-75		7.45	2890	149	117	293	5120	128	598		8.6
G3	Geothermal #3	01-07-75	93.0	6.85	2050	190	76.8	52	3274	30	314	96.6	10.3
	elev. 600' depth 550-600'	07-21-75			2000	195	81	59	3410		335		7.3
G3-T	Geothermal #3[(c)] (Thief)	07-21-75	74	1.4	1740	158	71	62.5	2980	20	317		9.1

(a) All concentrations are in mg/ℓ

(b) Suspect datum

(c) This sample taken 50-60' below water surface

(d) Tritium reported in tritium units

Source: Kroopnick, et al. (1978)

the cooler fresher water, reducing the lens effect and increasing the salinity and temperature of the basal water.

4.0 Site Specific Hydrology

The Kilauea Middle East Rift GRS has been grouped with the Kamaili Section of the Kilauea Lower East Rift GRS for purposes of discussing the site specific hydrology. The Kapoho Section of the Kilauea Lower East Rift GRS is geographically separate from the other zones and has distinguishing hydrologic features.

Very little site specific hydrologic information is available for the Kilauea Middle East Rift GRS and the Kamaili Section of the Lower East Rift GRS, primarily because economic necessity has not prompted detailed investigations. The nearest wells are the Pahoa wells (2986) just north of the Kamaili Section, and the Keauohana wells (2487) just south of the section (Figure IV-13). These wells are similar in depth (740-805 feet) and both are used for domestic supply purposes. The Pahoa wells produce water of excellent quality. It is anticipated that this is generally representative of all areas within these subzones which are northwest of the rift structure. It is thought that groundwater north of the rift zone flows to the ocean in a northeasterly direction, generally perpendicular to topographic contours (Fluor Technology, Inc., 1987).

The Keauohana wells (2487) are somewhat warmer and more saline (Table 4.12). It is anticipated that groundwater in and south of the rift zone in this area will be somewhat saline, depending upon the extent of seawater intrusion and geothermal leakage into the aquifer. Discharge to the ocean from this aquifer is expected to be direct in a southeasterly direction.

More information is available for the Kapoho Section of the Lower East Rift GRS as a result of the development of HGP-A and other geothermal wells within the section. The hydrology of this area is influenced by the major structural break (transverse fault) of the East Rift Zone at the southwest end of the section. All groundwater downgradient of the transverse break appears to be geothermally affected, displaying elevated temperatures and mineral levels (Fluor Technology, Inc., 1987).

South of the rift zone, groundwater flows southwest to the ocean. Permeability in the area is high, with the exception of the ash layer found near Kapoho Crater.

All water wells within and south of this section display elevated temperatures and relatively high mineral contents suggesting geothermal influence and a poorly developed basal lens. There are no recorded water wells north of the section, but the high quality of water from Pahoa wells suggests that groundwater quality may improve in a northerly direction.

HGP-A, the first successful geothermal well drilled in the East Rift Zone, initially produced much fresher fluids than would be predicted by the Ghyben-Herzberg model. This suggests that the dike system hinders the flow of seawater into the rift zone. The geothermal reservoir tapped by HGP-A differs from shallow well water in several respects. First, it has a high acidity with a pH value of about 3 compared to pH values of 7 or greater for shallow wells. Second, it has a silica content of 440 mg/liter compared to 80 mg/liter for shallow wells. Third, it has a very low tritium content, which indicates a relatively long residence time, possibly exceeding 50 years (Towill, 1982a). This suggests very limited interaction between the geothermal reservoir and the shallower groundwater aquifers.

The chemical composition of HGP-A fluids has changed considerably since the well was first sampled, as indicated by Table 4.13. This data suggests that either the seawater component of the reservoir has been increasing as fluids have been discharged from it or that the flash front is migrating out into the formation (Thomas, 1982a).

5.0 Potential Impacts to Groundwater Resources and Mitigation

Impacts to the groundwater would be the result of activities that occurred during exploration, development, well testing, and operation of the geothermal power plant.

Impacts to the groundwater during the exploration and development phases are expected to be limited and of short duration. In order to establish a reference base for water quality, groundwater in the vicinity of each well should be tested during drilling. Clearing and construction activities would not be expected to have any impact on surface or groundwater quality within or adjacent to the project areas. Developers should establish procedures to minimize the effects of accidental spills of materials such as oil and gasoline.

The impact to the groundwater by a release of drilling mud (a mixture of clays with materials added such as barite and sodium hydroxide to provide correct density, chemistry and lubricating characteristics) would be expected to be minimal due to the relative immobility and mostly benign nature of the mud (Towill, 1982a).

During normal drilling operations, geothermal wells are drilled past groundwater aquifers and well casings are set and cemented through subsurface formations containing the basal water lens. All drilling, casing installation, maintenance and

Table 4.13 CHEMICAL COMPOSITION OF THE HGP-A RESERVOIR FLUIDS

Date	Cl	Na	K	Mg	Ca	SiO_2	CO_2	H_2S
1-08-76	876	480	84.8	0.200	32.8	-	-	-
4-11-77	1220	584	106.4	0.100	30.9	404	-	-
6-12-81	637	322	61.6	0.021	7.4	408	600	450.0
9-04-81	2109	1248	143.0	0.060	41.0	456	538	409.0
4-19-82	3017	1591	269.0	0.076	70.1	455	559	387.0
7-12-82	3445	1881	306.0	0.041	89.5	466	540	389.0
2-15-83	4260	2883	373.0	0.087	142.5	-		-
4-18-83	4392	2883	366.0	0.096	156.0	467	538	412.8

Source: Imada (1984)

abandonment of geothermal wells and reinjection wells are regulated and would be monitored to protect the groundwater aquifer (DLNR, 1984).

Surface and groundwater are likely to be impacted to some extent should unexpected events develop during drilling operations. Deep saline waters from the geothermal reservoir could migrate up the well bore into near surface waters, if proper casing and cementing practices have not been followed. Also, geothermal fluid could be vented to the surface in the unusual event of a well "blowout". The installation of "blowout" preventers on all well heads has achieved the desired safety objective in this type of operation elsewhere and only a few reported "blowouts" have occurred during all the geothermal drilling conducted around the world. The potential for contaminating surface or groundwaters from either of these events is considered minimal because regulations governing drilling of deep geothermal wells are stringent and are intended to prevent such occurrences (Towill, 1982a).

The usual procedure, in the case of an unsuccessful deep exploratory well, is to seal it off by pumping one or two cement plugs into it. All surface piping and equipment would be removed, leaving only a small concrete pad. Thus, any environmental effects of exploratory drilling should be erased within a few years after the site has been abandoned (Thomas, 1982a).

<u>Well Testing Impacts and Mitigation</u>. The potential impact of geothermal fluid being discharged on the surface for several days to several weeks during well testing would depend on the dissolved salt content of the fluid being discharged and the number of wells being tested simultaneously. The geothermal fluids from HGP-A well are the only geothermal fluids in Hawaii that have been sampled and analyzed. Geothermal fluids at other locations in Hawaii may have very different chemistries.

Based on the HGP-A well chemistry, the brines would not be toxic to groundwater. The rate of discharge, approximately 125 to 250 gpm, on the surface during well venting at a single well site would be relatively small. The discharged brine would be diluted by high rainfall and rapidly absorbed into the porous surface.

The brines at the HGP-A well were originally similar to dilute (15 percent) seawater, with a chloride concentration of approximately 2200 ppm and a TDS of 5800 ppm. Brine temperature was 300°F at the surface. Higher acidity and silica contents and a lower tritium content were also confirmed. As of 1982, the chloride concentration had increased from the original 2200 ppm to 6000 ppm (Thomas, 1982a).

During extended well testing, the quantity of discharged fluid would be more extensive. The major element concentrations found in HGP-A brines do not meet EPA drinking water standards.

The amount of discharge from each well site would be small in relation to the rainfall recharge in the areas. The average rainfall per acre, based on 100 inches per year, amounts to 7,439 gallons per acre per day. At this rate, the rainfall on 800 acres, (the approximate size of each development area) available for recharge to various aquifers is 5,951,200 gallons per day (gpd). The majority (approximately 70 percent) of this rainfall would infiltrate into the permeable rock and recharge the volcanic aquifer.

The amount of brine discharged per well site, based on HPG-A discharge rates of 150 gpm, is 216,000 gpd. After 1995, several well fields may be under simultaneous development. As a worst case, it appears possible to have up to four wells being developed or tested simultaneously, although this would be limited by the number of drilling rigs available for simultaneous operation and by the length of time needed to drill each well. If all four wells were in the same development area and were being tested simultaneously, the total discharge would be 864,000 gpd, approximately 17 percent of the total recharge within a development area, and the groundwater could experience a localized impact. Assuming 6000 ppm chlorides for the brines and 1000 ppm chlorides for the groundwater, the discharge could result in a localized increase to 1850 ppm chlorides.

This potential impact would be mitigated by:

- o The likelihood that in most cases only one or two wells would be drilled and tested simultaneously within an development area.
- o The high annual rainfall over large areas that would limit the above mentioned effects to localized areas.
- o The generally low existing quality of the hydrothermally altered groundwater, ranging from 750 to 7500 ppm chlorides. In fact there are no known wells producing good quality water at or downgradient from the rift zone.
- o Isotope studies indicate that the groundwater system is very active, with residence times on the order of one to two years. Localized effects would

be relatively quickly "flushed" away by new recharge.

Operation Impacts and Mitigation. The operation of power plants and production wells could have impacts derived from drilling of replacement and injection wells, from well testing, from emissions during normal plant operations and from a system failure. Measures to mitigate potential impacts on surface and groundwater from continued emissions during normal power plant operations should be incorporated, primarily in the design of the power plant and the abatement systems, in such plants after analysis of the geothermal fluid (Towill, 1982a).

The power plant, production wells, brine injection wells, and process fluid well operations would not impact surface or groundwater aquifers. The wells would be cased in steel and cemented throughout the shallower depths (Fluor Technology, Inc., 1987). Pressure and flow rate sensing devices would be incorporated between well heads and power plants to enable immediate detection of a rupture in a fluid pipeline so that immediate corrective action could be taken to shut in or divert the well or wells supplying that pipeline. Backup pumps would be incorporated in fluid disposal systems that control flows between condensers and cooling towers and reinjection of spent brine into the injection well. Such backup systems would minimize the chance of overflow or spill due to a primary pump system failure (Towill, 1982a).

Three methods have been considered for the disposal of spent geothermal fluids: (1) evaporation and percolation; (2) disposal at sea; and, (3) reinjection. Evaporation and percolation is the method in use at the HGP-A plant because the amount of effluent is small so that this method is feasible. Disposal of effluent at sea is not a consideration due to environmental and economic factors (DLNR, 1984).

The reinjection of spent brines and other solids back into the reservoir via injection wells is the only method under serious consideration, due to the volume of brines that will be produced (Thomas, 1982a; DLNR, 1984). The HGP-A power plant is designed to produce approximately 3 MW from one well. Each GRS could have three to four (or more) development areas (one power plant per development area) with three to four wellfields in each development area. A wellfield could contain as many as six wells. The amount of discharge per day at each development area, based on four power plants with approximately 17 wells per power plant (the number of 3 MW wells required to generate 50+ MW per development area) pumping 150 gpm each, is 14,688,000 gpd.

Between 60 and 75 percent of the brine discharged from all GRS would be returned to the deep rock geothermal reservoir below the 4,000-foot level. The volume of the effluent to be reinjected, based on 17 wells per power plant at each power plant injection site, would be approximately 2550 gpm. This rate of injection, based on the generally high regional hydraulic conductivity of basaltic rocks, could be readily accepted by the deep subsurface formations without excessive hydraulic response (i.e. high regional pressure head rises, although there may be some localized relatively high increases in pressure at the injection points). The total input via reinjection would be less than the output from geothermal wells and the temperature of the reinjected brine would be lower, resulting in a net reduction in the regional total potential. This reduction would probably result in increased leakage of water from the overlying dike confined groundwater and less of a tendency for thermally induced upward movement of the more brackish and warmer groundwater in the geothermal resource zone.

The reinjection could help to prolong the life of the geothermal resource by returning unused heat to the resource zone. At this time, however, the pace of magmatic activity is such that the geothermal resource, for practical purposes, might be considered self renewing.

6.0 Potential Site-Specific Groundwater Impacts and Mitigation

<u>Kapoho Section of the Kilauea Lower East Rift Zone.</u> There is no permanent surface water in this section, except at Green Lake in Kapoho Crater. The groundwater immediately below the LERZ has been found to be brackish and at temperatures of $90^{\circ}F$ or higher. This water is generally unsuitable for domestic or agricultural use (Towill, 1982a). All groundwater downgradient of the transverse break or fault appears to be brackish. The only fresh water occurrences are either outside the rift zone or upgradient from the transverse structural break area (Fluor Technology, Inc., 1987). Therefore, should the constituents of the geothermal fluids be found, by testing, to be benign or similar to brackish water existing in the vicinity of the wells, disposal of the effluent by reinjection should not impact groundwater resources in the area (Towill, 1982a).

<u>Kilauea Middle East Rift GRS and Kamaili Section of the Kilauea Lower East Rift GRS.</u> There is no permanent surface water in either of these sections. There is also very little site specific groundwater information available for this area. The nearest wells are the Pahoa wells just to the north and the Keauohana wells just to

the south of the section. The Pahoa wells produce water of excellent quality while the Keauohana wells produce warmer and more saline water. This pattern is thought to be generally representative of groundwater quality within these subzones. Water sampling and well monitoring should be performed during well installation to determine the hydrological characteristics of the local groundwater and of all aquifers encountered during drilling. Monitor wells downgradient from geothermal development activity would increase the probability of early detection of any potential undesirable effects on groundwaters.

D. NOISE

1.0 Existing Conditions

The potential impact of geothermal development on local noise levels is dependent on several variables including the intensity of the noise source, meteorological conditions, sound propagation conditions, and background noise. This section presents a discussion of background noise conditions in the Puna geothermal resource subzones.

Local terrain and vegetation features have a large effect on noise levels since terrain and vegetation can act as noise buffers. The geothermal subzones exhibit a large variation in terrain features and vegetation. Vegetation varies from light to dense, consisting of papaya orchards, woodlands, other natural vegetation, and barren lava (Fluor Technology, Inc., 1987). The terrain in the subzones is also quite varied. One feature which would have significant local noise shielding effects consists of several volcanic hills (puus). Each puu in the vicinity of a geothermal power plant or noise receptor would potentially reduce noise impacts.

Noise measurement data for the GRS is limited. An environmental noise survey was conducted by Fluor Technology, Inc. (1987) as part of the Puna Geothermal Venture (PGV) Project Environmental Impact Statement (EIS) noise impact analysis. This data will be used to characterize the typical environmental noise levels expected at suburban areas within the geothermal development subzones.

Noise monitoring stations were located at two residential locations near the PGV site. Background noise levels during the survey ranged from 34.2 dBA (7 PM) to 53.2 dBA (5 AM), which exceeds the County nighttime noise guidelines of 45 dBA. The high background noise level was due to moderate winds and precipitation in the area during the noise survey. Monitored noise levels from the PGV study are presented in Table 4.14. In general, background noise levels remained well below 45 dBA during most hours of the survey.

The Occupational Safety and Health Administration (OSHA) requirements for the workplace specify that no worker should be exposed to 115 dBA for more than 15 minutes, or to 90 dBA for more than eight hours. The U.S. EPA (1978) recommends that "noise limitations should conform, as an initial minimum, to the regulations issued by the U.S. Geological Survey for geothermal operations on Federal lands; i.e., not to exceed 65 dBA at the lease boundary or one-half mile from the source, whichever is greater."

Table 4.14 NOISE MONITORING DATA

Time Period (Hour Ending)	Off-Site Residence Brees Station L90[a] (dBA)	Off-Site Residence Brees Station Leq[b] (dBA)	Off-Site Residence Gilman Station L90[a] (dBA)	Off-Site Residence Gilman Station Leq[b] (dBA)
13:00	36	51.8	---	---
14:00	35	43.9	36	53.3
15:00	35	43.3	34	46.7
16:00	34	42.7	32	40.7
17:00	35	44.6	32	59.2
18:00	33	43.2	35	37.1
19:00	32	34.2	40	43.7
20:00	35	36.7	50	52.1
21:00	34	36.6	39	41.8
22:00	34	35.8	39	41.2
23:00	34	36.0	38	44.8
0:00	35	36.8	41	44.5
1:00	35	37.0	42	44.3
2:00	35	37.2	44	49.4
3:00	35	37.0	48	50.1
4:00	35	37.1	49	51.9
5:00	34	36.6	51	53.2
6:00	34	36.4	50	52.2
7:00	35	46.4	43	47.3
8:00	34	43.9	35	43.8
9:00	34	46.8	36	43.3
10:00	34	48.4	35	42.9
11:00	37	43.6	34	43.8
12:00	40	46.3	33	43.0
13:00	---	---	34	51.2

[a] L90 is the A-weighted sound pressure level that is exceeded 90 percent of the time. The specified time period is one hour. The L90 is commonly used as an indicator of the ambient background noise level.

[b] Leq is the equivalent sound level, which is the energy average of the a-weighted sound pressure level. The specified time period of one hour. The energy average is the constant noise level for an hour that has the same energy as the actual fluctuating level during the hour.

2.0 Noise Impacts and Mitigation

There are currently no noise standards with numerical limits in effect. The County of Hawaii Planning Department has developed Geothermal Noise Level Guidelines based on a noise study in the Puna District. These guidelines are based on U.S. Environmental Protection Agency noise criteria and could be applied to projects within the GRS.

The U.S. Environmental Protection Agency (U.S. EPA) recommends that noise limitations should conform, at a minimum, to the regulations issued by the U.S. Geological Survey for geothermal operations on Federal lands. These regulations require that noise levels not exceed 65 dBA at the lease boundary or one-half mile from the source, whichever is greater (U.S. EPA, 1978). As a reference, the U.S. EPA (1978) has set forth ranges of "well-known" sources of sound. Some of these ranges are:

o quiet wilderness area	20 - 30 dBA
o quiet suburban residence	48 - 52 dBA
o business office	50 - 60 dBA
o noisy urban area	80 - 90 dBA
o adjacent to freeway	90 dBA
o jet airplane at 100 feet	120 - 130 dBA

Noise guidelines are presented in units of average frequency weighted decibels (dBA) to account for human response to a range of sound frequencies. The County of Hawaii Planning Department noise guidelines specify 55 dBA during the daytime (0700 to 1900) and 45 dBA during the nighttime (1900 to 0700) as satisfactory for residential areas. Short duration (less than 1 second) impact noise limits are 10 dBA higher than the daytime and nighttime limits but may not be exceeded more than 10 percent of the time in any 20-minute period.

Noise Attenuation Calculations

Noise or sound may be described as a propagating disturbance through a physical medium (air). The sound is perceived by the ear as a pressure wave superimposed upon the ambient air pressure of the listener. The sound pressure is therefore the incremental variation about the ambient atmospheric pressure.

In a quiet, perfect atmosphere, normal expected attenuation is 6 decibels per doubling of distance (6 dB/dd) from the acoustic center of the noise source (spherical spreading rule) (Burgess, 1980). For this assessment, normal noise attenuation was calculated using the following equation:

$$Lp_2 = Lp_1 - 20 \log \left[\frac{d2}{d1}\right] \quad dB \qquad (1)$$

Where: L_{p2} = attenuated sound level

L_{p1} = source sound level (at 15m from source)

d_1 = distance of source measurement from center of acoustic sphere (generally 15m)

d_2 = distance of receptor from noise source

Field measurements have shown that noise attenuation is actually greater than 6 dB/dd. Sound waves, propagating through the air or any other medium, experience attenuation. This attenuation results from a partial absorption of the acoustic energy by the propagating medium. This additional attenuation is called excess attenuation. Excess air attenuation is important where long distances are involved and was calculated using the following equation:

$$A_{ex} = 7.4 \cdot \left[\frac{f^2 r}{\phi}\right] \cdot 10^{-8} \quad dB \qquad (2)$$

Where: A_{ex} = excess attenuation (dB)

f = geometric mean frequency of the band (Hz)

r = distance between source and receiver (m)

ϕ = relative humidity (%)

For this analysis, it was conservatively assumed that the relative humidity was 100 percent allowing for the least amount of atmospheric absorption.

Cumulative noise impact scenarios require the addition of noise levels from several sources. The following equation was used to calculate noise impacts from more than one source at each receptor:

$$L_{pt} = 10 \log [\Sigma\, 10^{L_{pi}/10}] \quad dB \qquad (3)$$

Where: L_{pt} = total sound power level

L_{pi} = ith sound power level

Single Geothermal Power Plant Noise Scenarios

Noise associated with geothermal power development would result from construction activities, well drilling, well workover, power plant operation, and power plant decommissioning. Noise impacts from each of these activities are presented below for single power plants. It was assumed that spacing of individual geothermal power plants would be large enough to preclude cumulative noise impacts.

Power Plant Construction and Decommissioning: Power plant construction noise would result from a wide variety of activities. Noise levels from equipment that would contribute to construction noise impacts are presented in Table 4.15. Most construction activities would normally take place during weekday daylight hours. The largest contributor to noise impacts would be from heavy diesel equipment. Noise levels resulting from construction activities would drop below 55 dBA within a distance of approximately 800 meters. These impacts would also apply to power plant decommissioning since the activities would be similar.

Well Drilling and Workover: Noise resulting from well drilling and workover activities would be minimal. All equipment associated with the drill rig would be acoustically insulated to reduce noise. Table 4.16 presents the noise levels associated with well drilling equipment. It was assumed that these activities would occur during all hours of the day or night. Noise levels associated with well drilling would be expected to drop to below 55 dBA within a distance of approximately 450 meters and to below 45 dBA within a distance of 1350 meters. Noise levels from well workover equipment is shown in Table 4.17. As with the well drilling activities, well

Table 4.15 EQUIPMENT NOISE LEVELS - PLANT CONSTRUCTION NOISE
(Sound Pressure Levels in dB at 50 feet)

Equipment	No.	Equip. Usage Factor	Octave Band Center Frequency (Hz) 63	125	250	500	1000	2000	4000	8000	dBA
Bulldozer	1	0.27	103	97	88	83	84	79	74	69	89
Front-End Loader	1	0.10	100	94	85	80	81	76	71	66	86
Excavator	1	0.10	99	93	84	79	80	75	70	65	85
Mid-Size Crane	1	0.16	92	86	77	72	73	68	63	58	78
Small Crane	1	0.16	89	83	74	69	70	65	60	55	75
Air Compressor	1	0.85	100	94	85	80	81	76	71	66	86
Portable Generator	1	0.85	99	93	84	79	80	75	70	65	85
Motor Vehicles	4	0.10	91	85	76	71	72	67	62	57	77
Welding Machines	6	0.70	90	84	75	70	71	66	61	56	76

Source: Fluor Technology, Inc. (1987).

Table 4.16 EQUIPMENT NOISE LEVELS - WELL DRILLING NOISE
(Sound Pressure Levels in dB at 50 feet)

Item	Octave Band Center Frequency (Hz) 63	125	250	500	1000	2000	4000	8000	dBA
Steady noise of specially quieted Barnwell drill rig, no steam venting noise	76	76	77	73	70	63	60	52	75
Maximum Pipe impact noise (b)	(a)	(a)	79	88	90	88	76	(a)	93
Steady noise from one diesel generator (b)	56	52	57	58	60	59	53	46	64

(a) Noise levels at this frequency would not contribute significantly.

(b) Maximum pipe impact noise is assumed to occur during 10% of the total drilling time (i.e., the equipment usage factor for the pipe impacts is 0.10).

Source: Fluor Technology, Inc. (1987).

Table 4.17 EQUIPMENT NOISE LEVELS - WELL WORKOVER NOISE
(Sound Pressure Levels in dB at 50 feet)

	Octave Band Center Frequency (Hz)								
Item	63	125	250	500	1000	2000	4000	8000	dBA
Steady noise of specially quieted Barnwell drill rig, no steam venting noise	76	76	77	73	70	63	60	52	75
Steady noise of thoroughly muffled steam during drilling	86	86	87	83	80	73	70	62	85
Maximum Pipe impact noise (b)	(a)	(a)	79	88	90	88	76	(a)	93
Steady noise from two air compressors with enclosures	83	83	80	73	65	62	60	58	75
Steady noise from one diesel generator (b)	56	52	57	58	60	59	53	46	64

(a) Noise levels at this frequency would not contribute significantly.

(b) Maximum pipe impact noise is assumed to occur during 10% of the total drilling time (i.e., the equipment usage factor for the pipe impacts is 0.10).

Source: Fluor Technology, Inc. (1987).

workover activities were assumed to occur during any hour of the day or night. Noise levels associated with well workover would be expected to drop to below 55 dBA within a distance of approximately 675 meters and to below 45 dBA within a distance of 2100 meters.

Power Plant Operation: Several sources would contribute to noise impacts during power plant operation. Noise levels from these sources are presented in Table 4.18. Since power plant units would operate continuously, noise impacts would occur during all hours. It was assumed that effective noise controls would be applied to the turbine, some piping, the H_2S abatement system, the NCG removal system, and other miscellaneous equipment. Noise impacts resulting from power plant operation would be expected to drop to below 55 dBA within a distance of 450 meters and below 45 dBA within 1300 meters. Noise levels during steam stacking episodes would not be expected to be much higher than normal power plant operation assuming a highly efficient rock muffler is used. Unpinned events, such as a rupture disk, could cause noise levels to reach 125 dBA at 15 meters and 83 at 1600 meters.

Cumulative Noise Impacts

Noise impacts resulting from cumulative geothermal power plant development are expected to occur. The phased development scenario and schedule, as proposed, would result in the sequential development of well fields and power plant construction approximately every year. Therefore, noise generating activities, like construction, well drilling, testing, and workover would not likely occur simultaneously.

To assess cumulative noise impacts from potential geothermal development, only noise levels resulting from geothermal power plant operation were considered. Using the data from Table 4.17, cumulative power plant noise impacts for the Puna geothermal region were estimated and are presented in Figure IV-14. These results indicate, on a worst-case basis, that noise levels greater than 55 dBA would only occur in the immediate vicinity of a geothermal power plant. Noise levels greater than 45 dBA would generally be limited to areas within the geothermal development subzones. These noise impacts would be acceptable based on U.S. EPA, and Hawaii County Planning Department guidelines, and are also well within the range of normal observed noise levels in the region.

Table 4.18 EQUIPMENT NOISE LEVELS - PLANT OPERATION NOISE
(Sound Pressure Levels in dB at 50 feet)

Item	Octave Band Center Frequency (Hz) 63	125	250	500	1000	2000	4000	8000	dBA
Turbine	69	69	65	63	60	58	53	45	66
Cooling tower per cell	78	78	75	72	68	65	62	54	74
H2S abatement system	75	69	65	79	77	66	56	45	80
NCG removal system (1-inch insulation)	(a)	74	73	73	37	75	76	69	81
Flow noise in steam pipes (b)	51	52	50	51	48	46	43	33	53

(a) Noise levels at this frequency would not contribute significantly.

(b) Includes acoustic insulation on steam piping.

Source: Fluor Technology, Inc. (1987).

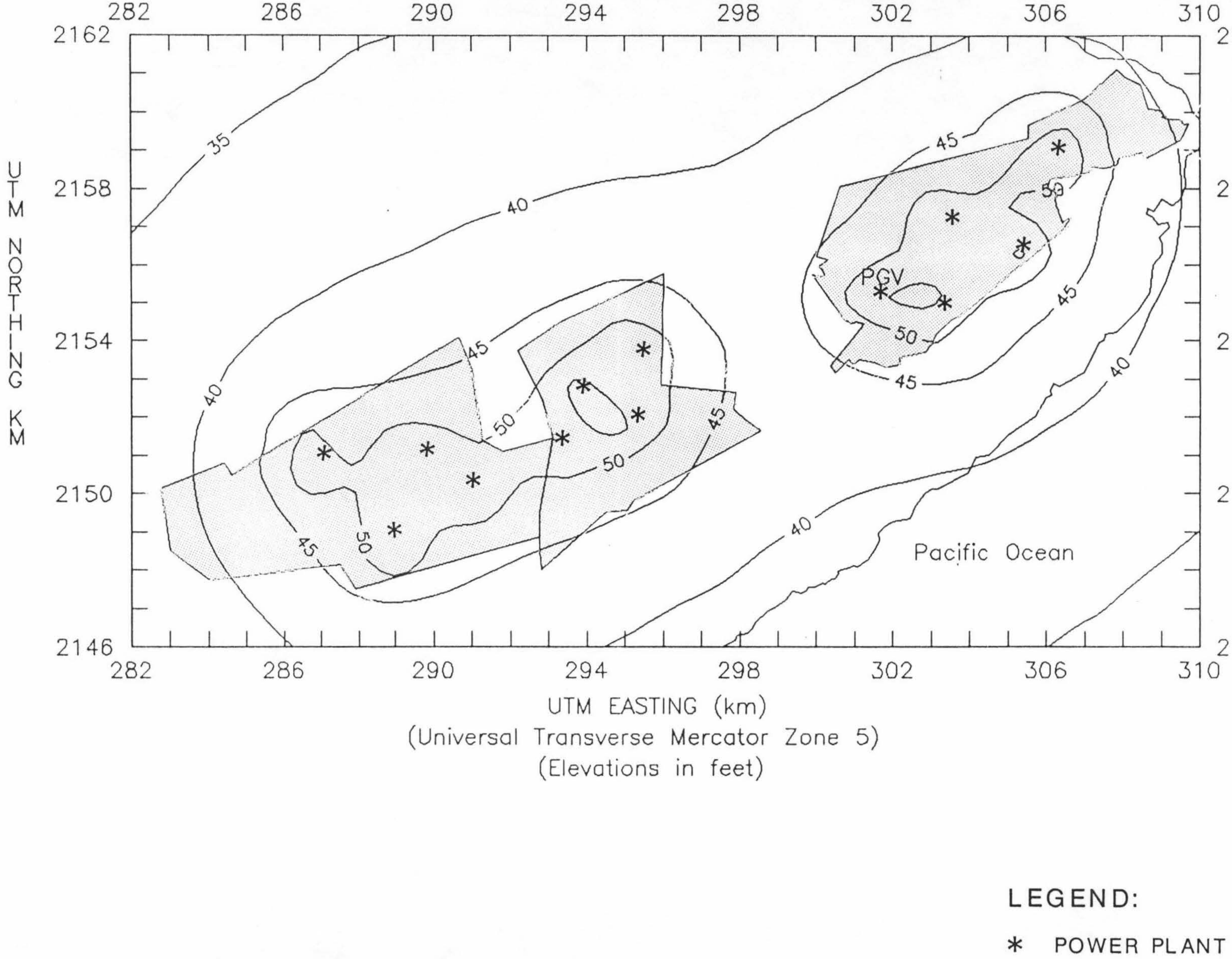


Figure IV-14

CUMULATIVE GEOTHERMAL POWER PLANT NOISE IMPACTS

Noise Mitigation Measures

Based on the above analyses, noise abatement mitigation measures should be applied where feasible to avoid potentially significant noise impacts. The Puna Geothermal Venture (PGV) project proposed several noise mitigation measures that should be considered for future projects.

Drilling Rig Noise:

- o Use residential-grade exhaust mufflers.
- o Place or construct acoustic enclosures around drill rig engines and any other noisy equipment.
- o Silence engine radiator air inlets and outlets.
- o Use effective rock muffler during flow testing and well workover activities.
- o Schedule excessively noisy activities, such as flow testing and well workover activities, during daylight hours.

Construction and Plant Decommissioning Noise:

- o Use highly efficient engine exhaust mufflers on all construction equipment and auxiliary equipment.
- o Set heavy equipment backup alarms to near minimum legal limit.
- o Limit all significant construction activities to daylight hours.

Operation Noise:

- o Insulate major pipes and valves with acoustically effective material.
- o Install silencers or rock mufflers on all pressurized steam outlets, when feasible.
- o Acoustically insulate steam injectors.
- o Orient plant layout to shield residents from noise and utilize landscaping to attenuate sounds emanating from plant operations.
- o Use state-of-the-art quiet fans, motors, and baffles for cooling towers.

- Use acoustical insulation and enclosures for turbine generator.
- Schedule all routine maintenance during daylight hours and avoid nighttime unscheduled maintenance where possible.

Implementation of the mitigation measures discussed above would help to avoid significant noise impacts on nearby residential and recreational areas resulting from drilling, construction, and operation noise.

PART V: BIOLOGICAL ENVIRONMENT

The primary objectives of the flora assessment were to (1) identify, describe, and map the major vegetation types within the GRS; (2) provide a checklist of plants inventoried from the GRS; and (3) identify Federal and/or State officially listed, proposed, and candidate threatened or endangered plant species within the GRS. The primary objectives of the fauna assessment were to (1) prepare a generalized description of the vertebrate and invertebrate communities within the GRS; (2) provide an annotated checklist of the vertebrate species within the GRS; and (3) identify Federal and/or State listed endangered species within the GRS.

A. METHODS

The information presented in this report is drawn largely from the existing literature. The primary sources for the biological information presented are the Puna Geothermal Area Biotic Assessment report prepared for DPED by Char and Lamoureux (1985a) and Jacobi's (1985) summary of biological information gathered during the U. S. Fish and Wildlife Service's Forest Bird Survey in Puna.

Other literature sources include biological surveys prepared for a number of Environmental Impact Statements and environmental assessments for geothermal projects and various other studies within the Puna area (Clarke et al., 1981; Ecotropics, 1981a, 1981b, 1981c, 1982; Conant, 1982a, 1982b; Lamoureux and Williams, 1982; Williams and Lamoureux, 1982; Towill, 1982a, 1982b; Char and Kjargaard, 1984; Char and Lamoureux, 1985b).

In addition, various government and private agencies, such as The Nature Conservancy, Hawaii, U. S. Fish and Wildlife Service, and the State Department of Land and Natural Resources' Division of Forestry and Wildlife, and individuals were consulted and provided additional information.

B. FLORA ASSESSMENT

Six major vegetation types occur on the lands which have been designated as Geothermal Resource Subzones. The distribution of these vegetation types is presented in Figures V-1, V-2 and V-3. Of the six vegetation types the 'ohi'a forest is further divided into four subtypes based on associated plant species, structure, disturbance, and the presence of introduced species. The 'ohi'a forests which have been less disturbed support a number of rare or endangered native plant and animal species.

The plant species list presented in Appendix C is drawn primarily from Char and Lamoureux (1985a) and from later surveys of lands in the Middle East Rift Zone (Char and Lamoureux, 1985b; Lamoureux, <u>et</u> <u>al</u>., 1988)

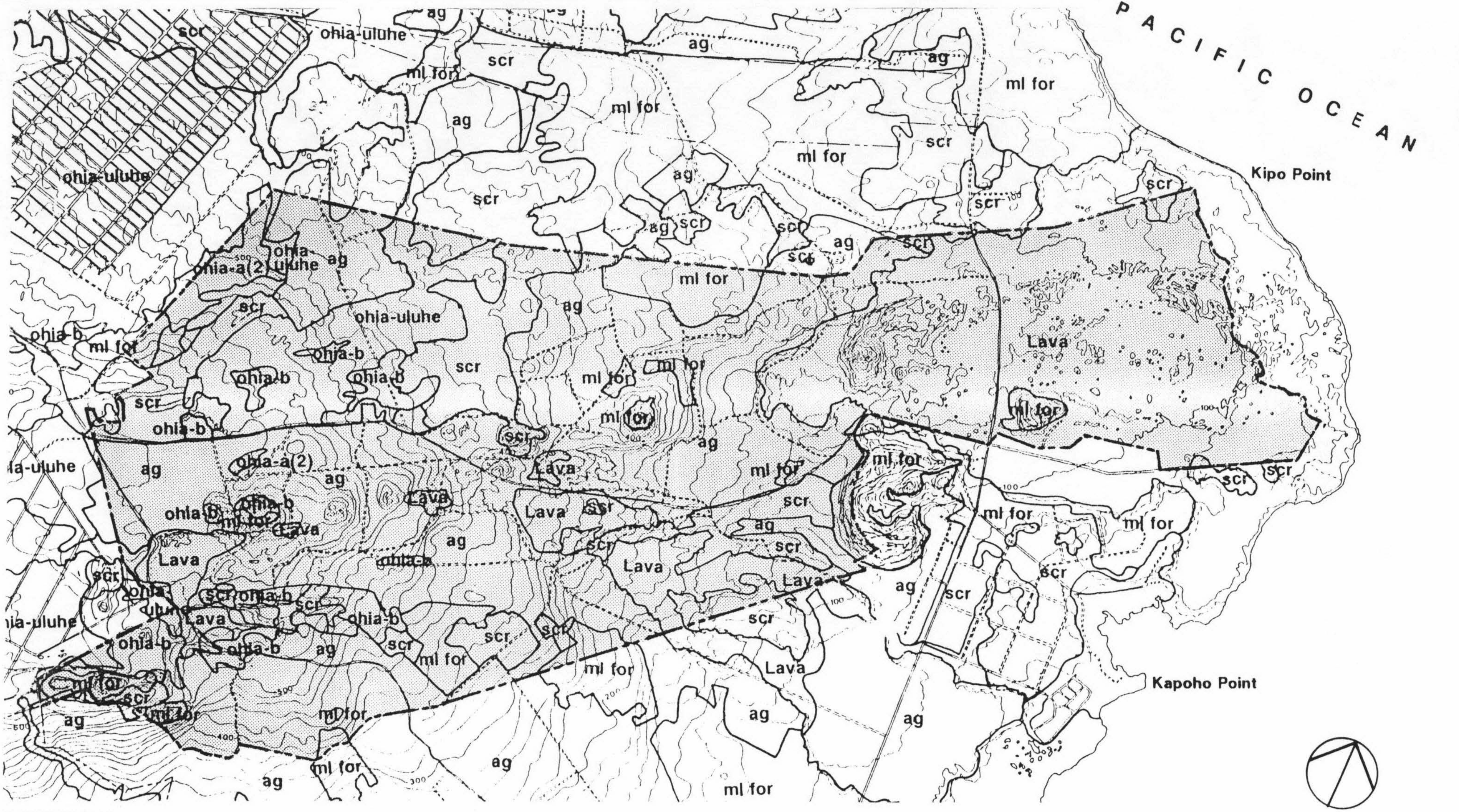
o <u>Lava</u>

Kilauea Volcano, a broad shield volcano lying against the southeastern slope of Mauna Loa, dominates the Puna landscape. Two rift zones extend southwestward and eastward from the caldera; most flank eruptions have taken place along these two rift zones, particularly along the later (Macdonald and Abbott, 1970).

The east rift zone runs the length of the study area and trends southeastward from the caldera for five miles but then bends sharply and extends east-northeastward to Cape Kumukahi and onward along the ocean floor (Macdonald and Abbott, 1970). Lava flows, pit craters, and spatter and cinder cones of different ages mark the east rift zone.

Lava flows of different ages can be observed within each of the different subzones. In wet areas such as Puna the development of vegetation is much more rapid than drier areas such as Kona. The whitish-gray lichen, <u>Stereocaulon vulcani</u>, often appears first on some lava flows; however, such plants as 'ohi'a (<u>Metrosideros collina</u>) and ferns such as sword fern (<u>Nephrolepis multiflora</u>) may also appear at the same time. 'Ohi'a is the most common pioneer among the flowering plants and may even appear before the lichens. On pahoehoe flows colonization by plants takes place mainly along joint cracks and fissures; on 'a'a flows plants are found scattered over the flow.

On the 1977 flow near the 1660 ft. elevation U.S.G.S. benchmark, plant cover on the 'a'a is very low, 1 to 2 percent. A few small 'ohi'a plants and sword fern may be found scattered here and there. Lichen cover is

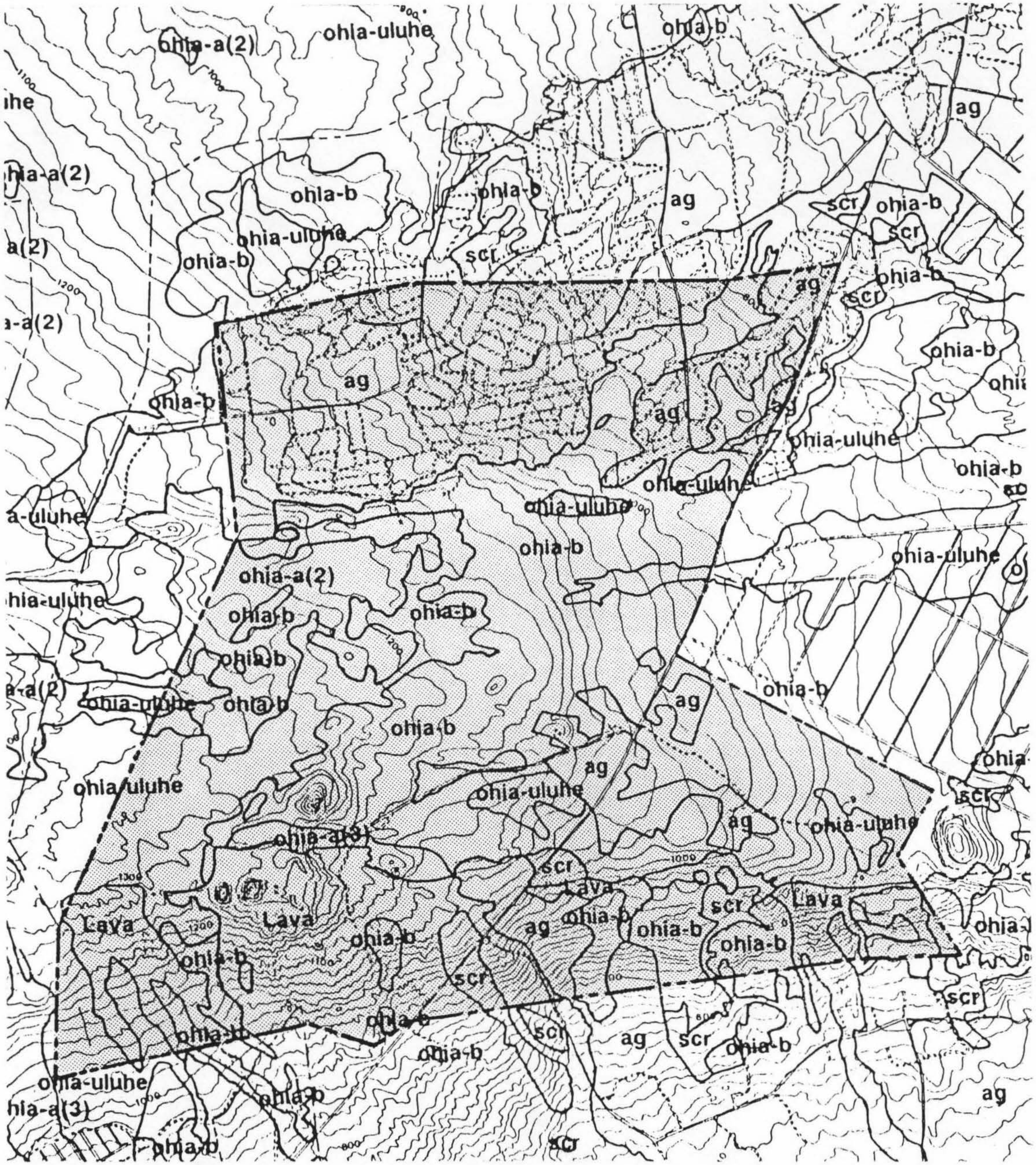


LEGEND:

ag	AGRICULTURE	ohia-uluhe	OHIA WOODLAND WITH ULUHE
scr	SCRUB	ohia-a(2)	WET OHIA FOREST WITH NATIVE SPECIES AND EXOTIC SHRUBS
ml for	MIXED LOWLAND FOREST		
Lava	LAVA	ohia-b	OHIA FOREST WITH EXOTIC SUBCANOPY AND SHRUB LAYERS

Figure V-1

VEGETATION TYPES IN THE KAPOHO SUBZONE



LEGEND:

ag	AGRICULTURE
scr	SCRUB
Lava	LAVA
ohia-uluhe	OHIA WOODLAND WITH ULUHE
ohia-a(2)	WET OHIA FOREST WITH NATIVE SPECIES AND EXOTIC SHRUBS
ohia-a(3)	OHIA-KUKUI FOREST WITH MIXED NATIVE AND EXOTIC SHRUBS
ohia-b	OHIA FOREST WITH EXOTIC SUBCANOPY AND SHRUB LAYERS

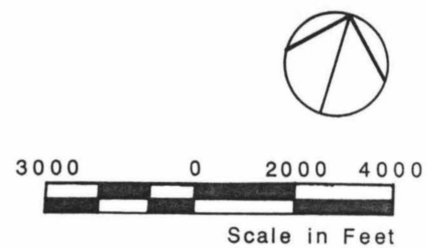
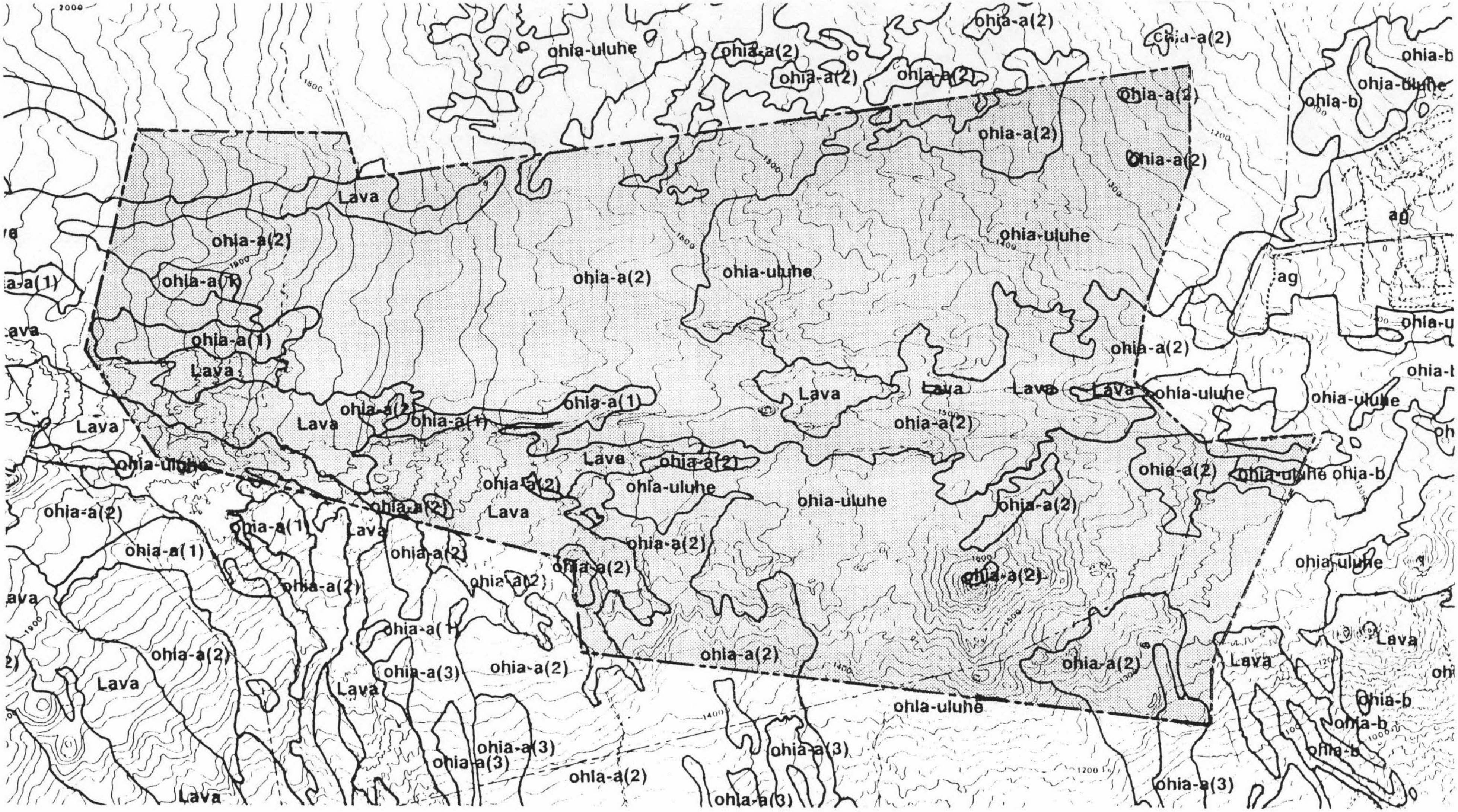


Figure V-2

VEGETATION TYPES IN THE KAMAILI SUBZONE



LEGEND:

Lava	LAVA	ohia-a(2)	WET OHIA FOREST WITH NATIVE SPECIES AND EXOTIC SHRUBS
ohia-uluhe	OHIA WOODLAND WITH ULUHE	ohia-b	OHIA FOREST WITH EXOTIC SUBCANOPY AND SHRUB LAYERS
ohia-a(1)	WET OHIA FOREST WITH NATIVE SPECIES		

3000 0 2000 4000

Scale in Feet

Figure V-3

VEGETATION TYPES IN THE KILAUEA SUBZONE

also low with Stereocaulon covering 30 to 40 percent of the rocky surface. Scattered throughout the flow are pockets of vegetation (kipukas) left more or less intact by the lava. These kipukas are of varying sizes. The larger kipukas usually survive with most of their components intact. The smaller kipukas usually have many of their 'ohi'a trees killed but still standing. Ferns such as uluhe (Dicranopteris spp.) and flowering plants such as mamaki (Pipturus hawaiiensis), Buddleja asiatica, and 'ohi'a often take root at the bases of these trees because these standing dead trees act as interceptors during driving rains, causing water to run down the trunks (Smathers and Mueller-Dombois, 1974). Tree molds scattered throughout the flow also provide shady, damp crevices where young plants may grow.

The 1955 flow between Keauohana Forest Reserve and 'I'ilewa Crater consists of 'a'a which is densely covered with Stereocaulon. Higher plant cover is 10 to 20 percent. Vegetation consists of 2 to 4 m tall 'ohi'a with many smaller individuals 15 to 30 cm tall and the introduced sword fern. Other species occasionally seen on the flow include bamboo orchid (Arundina bambusaefolia), broomsedge (Andropogon virginicus), moa (Psilotum nudum), and Buddleja. As one approaches the edge of the flow where it meets the forest, the percentage of plant cover and the number of species increases. Plants from the surrounding forests such as huehue (Cocculus ferrandianus), mamaki, uluhe, and 'uki (Machaerina spp.) slowly invade the flow from the forests.

o 'Ohi'a-Uluhe woodland

This vegetation type (designated as "ohia-uluhe" on the vegetation maps) covers large areas of Puna, especially on the relatively young lava flows below 1000 ft. elevation near Pahoa.

The 'ohi'a-uluhe woodland is interpreted as one of several stages in the normal succession leading to 'ohi'a forest on relatively wet 'a'a and pahoehoe flows. This vegetation type is often not uniform. Atkinson (1970) observed that even on the same flow there is a wide variation in the proportions of uluhe and 'ohi'a. It may vary from an uluhe "fernland" with few 'ohi'a trees to an 'ohi'a/uluhe "treeland"; gradations from "fernland" to "treeland" are not uncommon. Jacobi (1985) noted that the rate of vegetation development may be significantly influenced by the type of lava flow the plants have to grow on. In wet habitats the fastest rate of development towards an 'ohi'a forest is found on broken lava substrates--'a'a or "shelly" pahoehoe.

In places the 'ohi'a-uluhe woodlands have been burned at some time or another (Atkinson, 1970) or logged (Char and Lamoureux, 1985b). These disturbed woodlands have large patches of broomsedge (Andropogon virginicus) scattered throughout; clumps or thickets of Malabar melastome (Melastoma malabathricum) and waiawi (Psidium cattleianum) are also common.

The dense fern cover prevents the establishment of many seedlings and as a result only a few scattered plants such as kopiko (Psychotria hawaiiensis), 'uki (Machaerina spp.), Malabar melastome, and bamboo orchid (Arundina bambusaefolia) are found in the thick uluhe mats. The uluhe may be up to 3 m tall in some places. This vegetation type is difficult (and dangerous) to botanize as the thick carpet of matted ferns often obscures the large earth cracks, fissures, and tree molds beneath.

o 'Ohi'a forest

This vegetation type covers extensive portions of the Island of Hawai'i and is the principal vegetation type found within the Geothermal Resource Subzones. The dominant tree in this forest is 'ohi'a or 'ohi'a lehua (Metrosideros collina); all three varieties of Metrosideros occur in these forests. However, on older substrates large trees of Metrosideros collina var. macrophylla are often dominant (Stemmermann, 1983).

The 'ohi'a forest, especially the least disturbed portions, is the principal habitat for large numbers and kinds of native birds. Many rare native plant species are also found in this vegetation type.

Four different kinds of 'ohi'a forest are recognized in this study and are described in the following sections. Where different kinds of 'ohi'a forests meet, there is very often no sharp boundary delineation and one kind may grade into the other.

- Wet 'ohi'a forest with native species (designated as "ohia-a(1)" on the vegetation maps and in the discussion). This kind of 'ohi'a forest occurs within the Kilauea Middle East Rift Subzone. At these lower elevations (1900 to 1000 ft.) these wet forests are fragmented by recent lava flows and 'ohi'a forests which have been disturbed to some extent.

  The wet 'ohi'a forest with native species is the least disturbed vegetation type within the study area and is the best example of a more or less intact wet native forest community. Exotic (or introduced) plant species confined primarily to the trailsides and within the forest (away from trails) are relatively rare or uncommon except where pigs have rooted or wallowed. Most of these exotic plants are grasses, sedges or herbs and include such species as Hilo grass (Paspalum conjugatum), broomsedge (Andropogon virginicus), Vaseygrass (Paspalum urvillei), Cyperus haspan, water purslane (Ludwigia palustris), Hypericum spp., Drymaria cordata and fireweed (Erechtites valerianaefolia). A few scattered shrubs of strawberry guava (Psidium cattleianum) may sometimes be encountered.

These wet 'ohi'a forests with native species are closed canopy forests (>60 percent cover) and are composed largely of mature, tall statured (>10 m) 'ohi'a trees. Trees with trunks 1 to 1.5 m in diameter are not uncommon.

Beneath the 'ohi'a trees is a subcanopy layer of native trees, 8 to 10 m tall which includes kawa'u (Ilex anomala), olapa (Cheirodendron trigynum), alani (Pelea clusiaefolia), and kopiko (Psychotria hawaiiensis). Trees of 'ohe (Tetraplasandra hawaiiensis) may sometimes be found, usually in the more open areas. Tree ferns (Cibotium spp.) form a third layer (3 to 5 m tall) which may be dense in places. A number of shrubs and smaller trees are found scattered among the tree ferns. These commonly include kanawao (Broussaisia arguta), pilo (Coprosma spp.), several Cyrtandra species, Clermontia parviflora, and 'akia (Wikstroemia sandwicensis). Patches of uluhe (Dicranopteris spp.) are found scattered throughout the forest, especially in areas where the canopy cover is more open. A large number of terrestrial and epiphytic ferns is found in this type of forest. Liverworts and mosses are abundant and form thick cushions on the trunks of trees.

At the lower elevations the composition of the subcanopy layer begins to change. Lama (Diospyros ferrea) and kopiko become the common elements of this layer while the tree fern layer begins to thin out. Only small portions of these lower elevation forests now remain intact. These forests are an important biological resource in understanding the dynamics of our native forests (Stemmermann, 1983; Mueller-Dombois, 1985).

- <u>Wet 'ohi'a forest with native species and exotic shrubs</u> (designated as "ohia-a(2)" on the vegetation maps and in the discussion). This forest type is found primarily in the Kilauea Middle East Rift Subzone. The ohia-a(2) forest is more or less similar in composition and structure to the less disturbed ohia-a(1) forest discussed previously. It may have a closed or open canopy. Exotic shrubs, primarily strawberry guava and Malabar melastome (<u>Melastoma malabathricum</u>) are found throughout the forest but are most abundant in areas which have been disturbed. Patches of uluhe and exotic grasses are also more frequently encountered. The tree fern layer is usually not as well-developed as in the ohia-a(1) forest.

Signs of pig activity are often found; feral cattle damage to 'ie'ie (<u>Freycinetia arborea</u>), 'uki (<u>Machaerina angustifolia</u>), and olapa may also be observed in these forests.

Parts of the ohia-a(1) and ohia-a(2) forests bordering the recent Pu'u O'o flows have suffered damage from heat, fire, and volcanic fumes and debris (tephra and ash). As a result, there is often a strip of vegetation, 5 to 10 m wide, of standing dead 'ohi'a trees bordering the lava flows. These areas are invaded by an assortment of weedy species such as sword fern (<u>Nephrolepis multiflora</u>), pluchea (<u>Pluchea odorata</u>), Hilo grass, <u>Buddleja asiatica</u>, and broomsedge. <u>Clidemia hirta</u>, a noxious weed, can be found in such areas in the Kilauea Middle East Rift Subzone.

Jacobi (1985) notes that this habitat contains a number of plants which have their distributions restricted to, or attain their greatest abundance, below 2,500 ft. elevation. Unique features of the lowland forests include the incorporation of such subcanopy and shrub species as 'ahakea (<u>Bobea timonioides</u>), mehamehame (<u>Antidesma platyphylla</u>), and olomea (<u>Perrottetia sandwicensis</u>). Certain of the <u>Cyanea</u> and <u>Cyrtandra</u> species are only found in these lowland forests.

Unfortunately, these lowland habitats have generally been heavily impacted by human activities in Hawai'i. Direct impacts include logging and clearing of forests; indirect impacts include habitat degradation by introduced animals such as pigs and cattle and introduced plants such as strawberry guava, Malabar melastome, and <u>Clidemia</u>.

It has been estimated that less than 10 percent of the original area of lowland 'ohi'a rain forest remains in the State today, and most of it contains at least a minor complement of introduced species (Jacobi, 1985).

- _'Ohi'a-kukui forest with mixed native and exotic shrubs_ (designated as "ohia-a(3)" on the vegetation maps). This forest type is similar to the ohia-a(2) forest but contains a certain admixture of kukui (_Aleurites moluccana_) trees and other exotic tree and shrub species (Mueller-Dombois, 1985). The wet 'ohi'a-kukui forest units are easily recognized on aerial photographs. The rounded, silvery-green colored kukui canopy appears as whitish, mottled areas on black-and-white photographs.

Kukui is a Polynesian introduction, and the Hawaiians most likely cultivated some parts of this forest. The 'ohi'a-kukui forests examined during the various botanical surveys contained plants of 'awa (_Piper methysticum_), 'awapuhi-kua-hiwi (_Zingiber zerumbet_), pi'ia (_Dioscorea pentaphylla_), Hawaiian bamboo (_Schizostachyum glaucifolium_), and ti (_Cordyline terminalis_). More recently introduced plants such as jackfruit (_Artocarpus heterophyllus_), avocado (_Persea americana_), and _Philodendron_ sp. are also found in these forests. Strawberry guava and Malabar melastome shrubs may form a dense understory in these forests.

- _'Ohi'a forest with exotic subcanopy and shrub layers_ (designated as "ohia-b" on the vegetation maps). Within the three geothermal subzones large areas are covered by 'ohi'a forests dominated by exotic subcanopy and shrub layers. The forests may consist of medium to tall stature trees with open or closed canopies. This type of forest is often hard to distinguish from the ohia-a(2) forests on the aerial photographs, especially if the canopy is closed. The understory layers of this type of forest have, at some time in the past, been more or less greatly disturbed as exotic species dominate.

Tall strawberry guava forms a dense subcanopy layer, 6 to 7 m tall, while smaller guava plants, 1 to 3 m tall, make up the shrub layer. Malabar melastome is usually a common component of the shrub layer. The ground beneath is usually heavily shaded and groundcover often consists of basketgrass, thimbleberry (_Rubus rosaefolius_), downy woodfern (Christella dentata), 'awapuhi-kua-hiwi, and strawberry guava seedlings of all sizes. Other exotics found in this type of 'ohi'a forest include honohono (Commelina diffusa), Spathoglottis plicata, fireweed, ti, pi'ia, a number of ginger species (Hedychium spp.), Hilo grass, and rose apple.

Native species such as lama, tree ferns, 'ie'ie, and kopiko are occasional to common. The more open areas of these forests are usually filled with tangled mats of uluhe.

o Mixed lowland forest

The mixed lowland forests (designated as "ml for" on the vegetation maps) are found on the lower elevations of the Kapoho subzone and are common throughout the lower Puna area. This vegetation type presents a varied mosaic of plant associations rather than an integrated entity. It is fragmented by villages, subdivisions, cultivated lands and lava flows.

The lowland forest contains many species found in the moist mesophytic 'ohi'a forest in addition to hala (Pandanus spp.), hau (Hibiscus tiliaceus), and other lowland species. Its inland boundaries are difficult to delineate as it overlaps other inland ecosystem types (Fosberg, 1972).

The lowland forests have been strongly modified by man. The Polynesians introduced trees such as niu (Cocos nucifera), kukui (Aleurites moluccana), kamani (Calophyllum inophyllum), 'ulu (Artocarpus altilis), milo (Thespesia populnea), and 'ohi'a-'ai (Syzygium malaccense). They also brought with them ohe (Schizostachyum glaucifolium), mai'a (Musa spp.), yams (Dioscorea spp.), taro (Colocasia esculenta var. antiquorum), 'ape (Alocasia macorrhiza), noni (Morinda citrifolia) and 'awa (Piper methysticum). These plants are frequently found associated with old Hawaiian house sites and agricultural terraces in Puna.

Later post-Cook introductions include trees and shrubs of Java plum (Syzygium cumini), mango (Mangifera indica), avocado (Persea americana), rose apple (Syzygium jambos), guava (Psidium guajava), strawberry guava (Psidium cattleianum), Christmas berry (Schinus terebinthifolius) and monkeypod (Samanea saman). Forestry plantings of trees such as albizia (Albizia spp.), ironwood (Casuarina spp.), gunpowder tree (Trema orientalis), Ceara' rubber (Manihot glaziovii), macaranga

(Macaranga spp.), Melochia umbellata, and guarumo (Cecropia spp.) were also made. Many of these introduced species have naturalized and spread.

The mixed lowland forests in Puna today are composed most frequently of a mixture of native trees--'ohi'a, lama (Diospyros ferrea ssp. sandwicensis), hala--and the introduced trees mentioned above. The heights of these forests vary greatly from low stature, almost scrub-like, disturbed forests to medium or tall stature older forests. The understory varies considerably depending upon the nature of past disturbances and the amount of canopy cover. The shrub layer may consist of the two guava species, Pluchea odorata, Malabar melastome (Melastoma malabathricum), Christmas berry, and the native shrubs kopiko (Psychotria hawaiiensis), mamaki (Pipturus hawaiiensis), and 'akia (Wikstroemia sandwicensis). Noni and hapu'u i'i (Cibotium chamissoi) are occasionally found. Where the understory has been greatly disturbed guava and/or strawberry guava may form a dense shrub layer.

Ground-cover is sparse when the canopy is dense. Basketgrass (Oplismenus hirtellus), 'awapuhi kua hiwi (Zingiber zerumbet), downy woodfern (Christella dentata), sword fern (Nephrolepis multiflora), and smaller shrubs of thimbleberry (Rubus rosaefolius) and Stachytarpheta spp. are commonly observed. Seedlings of the tree and shrub species are numerous. Where canopy cover is less dense such as in disturbed areas, along roadsides, and the peripheries of the forest, the ground cover is dense and may consist of California grass (Brachiaria mutica), molasses grass (Melinis minutiflora), napiergrass (Pennisetum purpureum), honohono (Commelina diffusa), and sensitive plant (Mimosa pudica var. unijuga). The vines maile pilau (Paederia foetida), ka'e'e (Mucuna gigantea), and white thunbergia (Thunbergia fragrans) are also common in these more open areas.

o Scrub

Designated as "scr" on the vegetation maps, this vegetation type is found in areas which have been frequently disturbed or previously cleared. It is usually dominated by exotic species. Scrub vegetation occurs primarily in the Kapoho subzone where there has been much more disturbance and agricultural activities.

The structure of this vegetation type may vary from open, grassy areas with scattered shrubs and trees to dense, closed scrub. Broomsedge (Andropogon virginicus), molasses grass (Melinis minutiflora), or California grass

(Brachiaria mutica) are usually the dominant grass species in the open scrub. Napiergrass (Pennisetum purpureum), bush beardgrass (Andropogon glomeratus), and Hilo grass (Paspalum conjugatum) may be locally common in some areas. The most abundant shrub species are Malabar melastome (Melastoma malabathricum) and the two guava species (Psidium guajava, Psidium cattleianum). Other shrubs commonly observed are lantana (Lantana camara), pluchea (Pluchea odorata), butterfly bush (Buddleja asiatica), and Desmodium cajanifolium. Scattered patches of uluhe (Dicranopteris spp.) may also be found in the scrub vegetation.

Very scattered low (<5 m) to medium (5 to 10 m) statured 'ohi'a trees may occasionally be found in some open scrub. Exotic trees frequently observed in the open scrub include Trema orientalis, albizia (Albizia spp.), Cecropia spp. and Melochia umbellata.

Solid stands of dense, almost impenetrable scrub composed most often of guava (Psidium guajava) and/or strawberry guava (Psidium cattleianum) are found wherever the land has been disturbed. Psidium reproduces and spreads rapidly from root sprouts. In some places this scrub can become as tall as 10 m or more and develop into a forest. Malabar melastome may also form dense scrub; however, this type of scrub does not get as tall as the Psidium scrub.

The density and diversity of the ground cover varies with the amount of light able to penetrate the scrub. The herb layer is poorly developed where the scrub is dense. Much of the ground is bare or covered with litter from the shrubs above. Shade tolerant plants such as basketgrass (Oplismenus hirtellus) and downy woodfern (Christella dentata) are found here. Where the scrub is less dense Glenwoodgrass (Sacciolepis indica), sword fern (Nephrolepis multiflora), thimbleberry (Rubus rosaefolius), Stachytarpheta spp., honohono (Commelina diffusa), as well as basketgrass and downy woodfern, are present.

Few native species are found in this vegetation type, and then these species tend to be found in the more open scrub. Besides 'ohi'a and uluhe, other natives sometimes found in the scrub include 'akia (Wikstroemia sandwicensis), lama (Diospyros ferrea ssp. sandwicensis), and sedges such as Fimbristylis dichotoma, 'uki (Machaerina angustifolia), kuolohia (Rhynchospora lavarum), Pycreus polystachyos, and Scleria testacea.

o <u>Agricultural lands</u>

Designated as "ag" on the vegetation maps, much of Puna, especially the lower Puna area, has been cultivated since prehistoric and historic times. All cultivated lands including sugar cane and papaya fields, orchards, anthurium and orchid farms, fallow fields, etc., as well as abandoned fields, pastures, and the network of roads associated with farming activities were designated "Agricultural lands" in the Char and Lamoureux study (1985a). Agricultural lands are found on the Kamaili and Kapoho subzones.

These agricultural lands present a mosaic of different patterns on the aerial photographs and are in a constant state of change from year to year. Different crops, stages of cultivation, fallow fields, crop rotation, and expansion of existing fields all contribute to the general dynamics of agricultural lands.

Sugar cane (<u>Saccharum officinarum</u>) and papaya (<u>Carica papaya</u>) have been the primary crops grown in the Puna region. However, with the closing of the sugar mill, many of these fields have been abandoned or turned over to papaya cultivation. These abandoned fields are in various stages of weedy succession.

Papaya fields in various stages of cultivation from newly transplanted seedlings to mature, bearing plants, 2 to 4 m tall, cover fairly large acreages, mostly in the Kapoho subzone. Abandoned papaya fields are also frequently found. Like the sugar fields, these abandoned papaya fields are in various stages of weedy succession. <u>Melochia umbellata</u> will often quickly invade these fields.

Long abandoned fields with their networks of roads and other evidences of human activities can still be delineated on the aerial photographs if they have not been obscured by the vegetation. Ground check of these areas reveals remnants of the former crops or the weedy tree and shrub species associated with abandoned fields.

Other crops grown in the Kamaili and Kapoho subzones include bananas (<u>Musa</u> hybrids), passion fruit (<u>Passiflora edulis</u>), guavas (<u>Psidium guajava</u> cultivars), and various cut flowers and foliage.

A number of weedy species are commonly associated with all these cultivated areas. These include several <u>Euphorbia</u> spp., false pimpernel (<u>Lindernia crustacea</u>), Ageratum conyzoides, Polygala paniculata, comb hyptis, and kyllinga. Many fields are periodically treated with herbicides to control these weeds.

Pasture lands are also included in this ecosystem type. They vary in structure and are very diverse in species compositions. For example, some pastures may be open savannahs with tall 'ohi'a trees on lands cleared of native forests or they may be scrubby if overgrazed. Most of the pasture grasses and herbs were deliberately introduced and specifically planted or sown to improve the pasture (Fosberg, 1972). Pasture grasses commonly seen in the study site include pangolagrass (Digitaria decumbens), narrow-leaved carpetgrass (Axonopus affinis), and Hilo grass (Paspalum conjugatum).

C. FAUNA ASSESSMENT

1.0 Vertebrates

Information on the vertebrate fauna resources is drawn from a number of different studies and reports. Avifauna occurrences are primarily from Berger's (1985) discussion of the avian resources presented in Char and Lamoureux (1985a), Jacobi's (1985) summary of bird species found during the USFWS Forest Bird Survey, Conant's (1982b) baseline survey of the birds in the Keahialaka-Pohoiki-Kapoho-Kula areas, Char and Kjargaard's (1984) survey report for Puna Geothermal Venture, and the EIS prepared for the Kahauale'a Geothermal Project (Towill, 1982a). Information on mammal distribution within the GRS was extracted from the last three references.

o Avifauna

Twenty-one bird species have been recorded from the Geothermal Resource Subzones. Of the six endemic species, the Hawaiian Hawk or 'I'o (Buteo solitarius) is the only listed endangered species. The endangered 'O'u (Psittorostra psittacea), considered to be the rarest of the surviving honeycreepers on the island of Hawai'i by the USFWS Forest Bird Survey team, has been observed on the adjacent Kahauale'a lands and the upper elevation portions (plus or minus 2,260 ft.) of the Puna Forest Reserve.

In general, the endemic species are associated with the less disturbed vegetation types found primarily on the Kilauea Middle East Rift Zone, although Conant (1982b) has observed a few 'Elepaio (Chasiempis sandwichensis), 'Amakihi (Hemingnathus virens), 'Apapane (Himatione sanguinea), and one 'I'iwi (Vestiaria coccinea) in forested areas of Kamaili and nearby Pahoa. The endangered Hawaiian Hawk occurs widely throughout the Puna District and over the GRS.

Table 5.1 summarizes the species present and their distribution within the GRS. An annotated species list of birds recorded from the Geothermal Resource Subzones follows:

Family:Accipitridae (Hawks) — Buteo solitarius, Hawaiian Hawk, 'I'o

The 'I'o is endemic to the island of Hawai'i, the only remaining species in a once diverse endemic raptor fauna (Olsen and James, 1982; Char and Kjargaard, 1984). The 'I'o is a

Table 5.1. LIST OF BIRDS RECORDED FROM THE GEOTHERMAL RESOURCE SUBZONES, PUNA DISTRICT, HAWAII

SPECIES	STATUS+	1*	2	3
Buteo solitarius Hawaiian Hawk, 'I'o	N,E	+	+	+
Phaeornis obscurus Hawaiian Thrush, 'Oma'o	N	+	−	−
Chasiempis sandwichensis 'Elepaio	N	+	+	−
Hemignathus virens 'Amakihi	N	+	+	−
Vestiaria coccinea 'I'iwi	N	+	+	−
Himatione sanguinea 'Apapane	N	+	+	−
Pluvialis dominica Lesser Golden Plover, Kolea	M	−	+	+
Callipepla californica California Quail	F	−	+	−
Phasianus colchicus Ring-necked Pheasant	F	−	+	+
Lophura leucomelana Kalij Pheasant	F	−	+	−
Tyto alba Barn Owl	F	−	+	+
Streptopelia chinensis Spotted Dove	F	+	+	+
Geopelia striata Barred Dove	F	−	+	+
Columba livia Rock Dove	F	−	+	+
Garrulax canorus Melodious Laughing-thrush	F	+	+	+
Zosterops japonicus Japanese White-eye	F	+	+	+
Acridotheres tristis Common Myna	F	−	+	+
Lonchura punctulata Spotted Munia	F	+	+	+
Passer domesticus House Sparrow	F	−	+	+
Cardinalis cardinalis Northern Cardinal	F	+	+	+
Carpodacus mexicanus House Finch	F	+	+	+

+STATUS: N = native, endemic to the Hawaiian Island
M = regular migrant visitor
F = foreign introduced species
E = endangered

*Recorded (+) or absent (-) from
1 = Kilauea Middle East Rift GRS
2 = Kilauea Lower East Rift GRS: Kamaili Section
3 = Kilauea Lower East Rift GRS: Kapoho Section

large, heavy-set bird with broad wings and a broad, relatively short, rounded tail; the male generally smaller than the female. Its plumage may be dark brown above and below or dark brown above and pale buff below, frequently streaked with darker feathers (Berger, 1972).

'I'o were frequently seen during the Puna Geothermal Biotic Survey (Char and Lamoureux, 1985a), occurring over a wide range of ecosystem types including agricultural lands, particularly papaya fields. The district of Puna supports a dense breeding population. The Puna area, particularly below 2,000 ft. elevation, is considered to include a major portion of the island-wide 'I'o population, estimated to be between 1,400 and 2,500 birds (Griffin, 1984; Jacobi, 1985).

Family:Turdidae (Thrushes and Bluebirds)	Phaeornis obscurus Hawaiian Thrush, 'Oma'o

The Hawai'i island race of the endemic thrush is the most common of the surviving races. Berger (1985) notes that the USFWS Forest Bird Survey team found fairly high numbers of 'Oma'o at lower elevations in Puna and Ka'u. The large numbers of 'Oma'o in mosquito-infested Puna indicate some populations have developed resistance to avian malaria. Berger notes that he has observed 'Oma'o as low as 1,000 ft. elevation in the Puna Forest reserve, primary site of the Kilauea Middle East Rift GRS. 'Oma'o were one of the most frequently encountered native species in the Upper Kalapana and Wao Kele O Puna Natural Area Reserve (Puna Forest Reserve) during the Puna Geothermal Biotic Survey (Char and Lamoureux, 1985a).

Family:Muscicapidae (Old World Flycatchers)	Chasiempis sandwichensis 'Elepaio

The 'Elepaio is one of the few native bird species that has been able to adapt to mixed endemic and introduced vegetation and even to almost entirely introduced vegetation in some lowland areas on O'ahu (Berger, 1985). It is a small bird, about 5 1/2 inches long, with upper parts brown and a white rump and dark tail (Hawai'i Audubon Society, 1984). Conant (1982b) found a few birds on the Kamaili Section, and it is most likely also present on the Kapoho Section where there is forest cover. Although it was not found in other previous surveys of the Kilauea Middle East Rift GRS, a rather large population of 'Elepaio was recently observed during a follow-up survey for a road alignment and power plant sites for the True/Mid-Pacific Geothermal Project (Lamoureux, et al., 1988).

Family:Drepanididae <u>Hemignathus</u> <u>virens</u>
(Hawaiian Honeycreepers) 'Amakihi

This is one of the most common of the surviving honeycreepers (Hawaii Audubon Society, 1984). The 'Amakihi is a small (4 1/2 inches long), yellowish-green bird, darker above. Its bill is dark and down-curved. Although it prefers the higher elevation, forested areas of the Kilauea Middle East Rift GRS, it has also been observed as low as 250 ft. elevation in the Malama Ki Forest Reserve by Berger (1985). Conant (1982b) recorded 'Amakihi in stands of native 'ohi'a forest in the Kamaili Section and Pahoa area. Given its occurrence in a wide range of elevations, it most likely also occurs on the Kapoho Section, particularly in the large tracts of 'ohi'a forests in the Halekamahina area and a portion of the Leilani Estates subdivision.

Family:Drepanididae <u>Vestiaria</u> <u>coccinea</u>
(Hawaiian Honeycreepers) 'I'iwi

With its bright vermilion-colored body, black wings, and long, curved salmon-colored bill, the 'I'iwi is one of the most striking in appearance of the surviving honeycreepers. It is fairly common on the island of Hawai'i, where the USFWS Forest Bird Survey team estimated a population of 340,417 birds. In the Puna District, however, the population has been estimated to number no more than 191 birds. Conant (1982a) reported 'I'iwi from the nearby Kahauale'a lands. 'I'iwi were observed in the Upper Kalapana and Wao Kele O Puna Natural Area Reserve (Puna Forest Reserve) portions of the Kilauea Middle East Rift

GRS during field studies for the Puna Geothermal Biotic studies (Char and Lamoureux, 1985a). A single sighting of 'I'iwi in or near the Pahoa area was recorded by Conant (1982b).

Family: Drepanididae (Hawaiian Honeycreepers) — <u>Himatione</u> <u>sanguinea</u>, 'Apapane

This crimson-colored bird with black wings and tail is the most common of the surviving honeycreepers. Population estimates of 132,023 birds have been given for the Puna area by the USFWS Forest Bird Survey team (Jacobi, 1985). 'Apapane occur over a wide range of elevations, from sea level in the Puna and Kona areas to about 9,000 ft. on Mauna Kea. 'Apapane have been recorded from the forests of the Middle East Rift Zone GRS and nearby lands (Conant, 1982a; Char and Lamoureux, 1985a; Jacobi, 1985; Lamoureux, <u>et</u> <u>al</u>., 1988). On the lower elevation parcels, 'Apapane have been observed from the Kamaili Section (Conant, 1982b). Like the 'Amakihi, the 'Apapane is also most likely to occur in forested areas of the Kapoho Section.

Family: Charadriidae (Plovers) — <u>Pluvialis</u> <u>dominica</u>, Lesser Golden Plover, Kolea

This golden-spotted, migratory shorebird returns to the Hawaiian Islands and other South Pacific island groups from its Arctic nesting grounds in late August. The birds winter over until March and April when they assume their breeding plumage--dark brown above; black below; white stripe over eye and side of neck -prior to leaving the islands. Wintering populations can be observed from sea level to 10,000 ft. elevation or higher (Hawaii Audubon Society, 1984).

Within the GRS, Kolea are widely distributed in fairly small numbers, being commonest on agricultural fields, roads and jeep trails, and other open areas within the Kamaili and Kapoho Sections.

Family:Phasianidae (Quails, Pheasants, Francolins) — Callipepla californica, California Quail

This game bird, introduced from the western United States before 1855, is commoner in the drier portions of the islands of Hawai'i, Maui, and Moloka'i. It is about 9 to 10 inches long, brown above with bluish-gray breast and buff-colored abdomen, noticeably scaled. A black plume on top of its head droops forward (Hawaii Audubon Society, 1984).

California Quail have only been recorded from the Kamaili Section (Conant, 1982b). As it prefers the drier areas, its occurrence within the GRS is probably rare.

Family:Phasianidae (Quails, Pheasants, Francolins) — Phasianus colchicus, Ring-necked Pheasant

Males are brightly colored--green heads; red wattles; white neck rings; bodies bronze and buff, heavily scaled. Females are brown with paler breasts and shorter tails. The Ring-necked Pheasant is found on all the main Hawaiian Islands, extending into the fringes of the rain forests. Birds have been observed by Conant (1982b) in the Kapoho and Kama'ili Sections.

Family:Phasianidae (Quails, Pheasants, Francolins) — Lophura leucomelana, Kalij Pheasant

The Kalij Pheasant is found in the forests of the island of Hawai'i, particularly the wet 'ohi'a-koa forests (Hawaii Audubon Society, 1984). It has been observed from 1,000 to 7,500 ft. elevation. The male is metallic bluish-black with white barring on the rump and gray breast feathers; the female is mottled with light and dark brown. Both have a rearward pointing head crest. The Kalij Pheasant has been recorded from the Kamaili Section (Conant, 1982b) and the Kilauea Middle East Rift (Kjargaard In Lamoureux, et al., 1988).

Family:Tytonidae (Barn Owls) — Tyto alba, Barn Owl

The Barn Owl is distinguished from the native Short-eared Owl or Pueo (<u>Asio flammeus sandwichensis</u>) by its heart-shaped face and light plumage. It is a relatively recent introduction to the Hawaiian Islands; the first birds were introduced to the Hamakua region, Hawai'i, in 1958. Small, exotic mammals, such as mice and rats, are the primary prey items of this species in the islands (Kjargaard <u>In</u> Char and Kjargaard, 1984).

The Barn Owl has been observed in the Kamaili and Kapoho Sections of the GRS. Kjargaard (<u>In</u> Char and Kjargaard, 1984) notes that this species probably occurs in low densities throughout the agricultural lands, though its nocturnal habits prevent accurate density estimation or determination of its distribution.

Family:Columbidae (Doves, Pigeons) — <u>Streptopelia chinensis</u> Spotted Dove

This Asian dove also known as the Lace-Necked or Chinese Dove was introduced to the Hawaiian Islands at an early date. The species is now common to abundant on all of the islands, and, like the other doves in the state, is classified as a game bird. Although this dove occurs where the rainfall exceeds 100 inches per year, the highest densities are found in drier areas where such introduced plants as koa-haole (<u>Leucaena leucocephala</u>) and kiawe (<u>Prosopis pallida</u>) flourish. Although a very common species on Hawai'i, the Spotted Dove is not an inhabitant of the wet 'ohi'a forests (Berger, 1985). The birds are about 12 inches long with both sexes similar in appearance--body grayish-brown with rosy breast and a band of black around sides and back of neck, spotted with white.

Within the GRS, this species prefers urban and open rural areas where it feeds on grass and weed seeds.

Family:Columbidae (Doves, Pigeons) — <u>Geopelia striata</u> Barred Dove

The Barred Dove or Zebra Dove was introduced from Asia in 1922 (Hawaii Audubon Society, 1984) and has since become abundant on all of the islands. The birds are about 8 inches long with both sexes similar--pale brown above, barred with black; breast rosy, soft gray below with barred side markings. Like the Spotted Dove, the Barred Dove is not an inhabitant of dense, wet 'ohi'a forests (Berger, 1985). They are most common in urban areas, and in relatively open rural areas such as papaya and cane fields, pastures, cut-over forests, and open scrublands.

Within the GRS, the Barred Dove has been recorded from the Kapoho and Kamaili Sections.

Family:Columbidae (Doves, Pigeons) — <u>Columba</u> <u>livia</u> Rock Dove, Pigeon

The Pigeon was first brought to the islands in 1796 (Berger, 1985). Several flocks of pigeons were observed by Berger (1985) in the lowland areas of the lower east rift zone. Berger does not mention whether these were feral (or wild) pigeons or domestic stock.

Family:Timaliidae (Babblers and Thrushes) — <u>Garrulax</u> <u>canorus</u> Melodius Laughing-thrush

According to Berger (1981; 1985) the species is native to the Yangtze Valley in China and southward to Laos, and it also occurs in Formosa. The birds were first brought to the islands as cage birds. Later, birds were released on Hawai'i and the other islands. The Melodius Laughing-thrush is now common on the island of Hawai'i, where the birds prefer fairly dense vegetation.

The birds are about 9 inches long, the sexes similar--large, rusty brown body with a prominent white eye ring and bar of white feathers extending behind the eye resembling spectacles (Hawaii Audubon Society, 1984). The birds are quite vocal, often scolding human intruders.

Melodius Laughing-thrush occur throughout the forested areas of the GRS. The Hawaii Forest Bird Survey estimated a population of roughly 3,146 birds for the wet forest habitats in their Puna study area (Jacobi, 1985; Scott <u>et</u> <u>al</u>., <u>In</u> <u>press</u>). The Melodius Laughing-thrush and the Japanese White-eye (<u>Zosterops</u> <u>japonica</u>) were the most frequently observed foreign birds in the more or less undisturbed 'ohi'a forests in the Kilauea Middle East Rift subzone (Char and Lamoureux, 1985a).

Family: Zosteropidae (White-eyes and Silver Eyes) — _Zosterops japonicus_ Japanese White-eye

The Japanese White-eye or Mejiro is a small bird, 4 1/2 inches long, olive-green with a conspicuous white eye ring. The birds were first released on O'ahu in 1929 and at least 252 birds were released on the island of Hawai'i during June 1937 (Berger, 1985). Berger (1985) comments that "... the White-eye presents an example _par excellence_ of the success of an introduced species. It now occurs on all of the main islands, is found from sea level to tree line on Hawai'i, and inhabits very dry areas (e.g., Kawaihae) and those having 300 or more inches of rainfall per year."

Within the GRS, the White-eye is ubiquitous throughout all vegetation types but prefers the forest areas. The Hawaii Forest Bird Survey estimated a population of 158,182 birds for the Puna study area (Jacobi, 1985; Scott _et al_. in press), making it the most abundant species encountered.

Family: Sturnidae (Mynas, Starlings) — _Acridotheres tristis_ Common Myna

This loud and aggressive, often comical, bird is native to India and was introduced into the islands in 1865 to control army worms that were ravaging pasturelands (Berger, 1985). Birds are about 9 inches long; head black with a patch of yellow skin around the eyes; breast and back brown; tail short and white-tipped; white wing patches conspicuous in flight (Hawaii Audubon Society, 1984).

The Myna is common to abundant in open areas of the GRS, such as agricultural lands, around buildings, road areas, and pastures. If found in forested areas, they are generally associated with open, disturbed patches or along the forest edge. The species is commensal with man and does not often stray from developed or impacted areas (Kjargaard _In_ Char and Kjargaard, 1984).

Family:Ploceidae (Weaverbirds and Allies) — *Lonchura punctulata* Spotted Munia

Also known as Nutmeg Mannikin or Ricebird. This species is about 4 inches long, the male with a dark brown face; upper parts brown; throat chestnut; breast and sides gray with dark crescents; the abdomen whitish. The female and juvenile birds are lighter brown with underparts buff. Berger (1985) notes that "... the Spotted Munia is an abundant species on all of the islands, and it is tolerant of both wet and dry habitats. The birds tend to be nomadic during the nonbreeding season, moving over large areas in search of seeds. The birds are prolific, nesting during every month of the year."

Within the GRS, the birds have been recorded from the Kapoho and Kamaili Sections (Conant, 1982b). The Hawaii Forest Bird Survey (Jacobi, 1985; Scott *et al*. in press) found birds in wet forest habitats in the Puna study area; this would include the Kilauea Middle East Rift subzone.

Family:Ploceidae (Weaverbirds and Allies) — *Passer domesticus* House Sparrow

This species is associated with man, being common in urban areas and often associated with buildings. This small, 6 inches long, gray and brown bird is omnivorous in diet, feeding on weed seeds as well as insects and their larvae and table scraps.

It is found throughout the Kapoho and Kamaili Sections wherever human beings and their homes or buildings are present.

Family:Fringillidae (Cardinals, Buntings, Finches) — *Cardinalis cardinalis* Cardinal

Also known as the Northern Cardinal or Kentucky Cardinal. The birds are about 9 inches long, the males red; the females reddish brown. The Cardinal is found on all of the main islands. On the island of Hawai'i, it is found from sea level to at least 7,500 ft. elevation on Mauna Kea (Berger, 1985).

Within the GRS, it prefers forested areas where it occurs along the forest edges, forest openings, and other disturbed areas.

Family:Fringillidae (Cardinals, Buntings, Finches) <u>Carpodacus</u> <u>mexicanus</u> House Finch

Also known as Linnet or, locally, as Papayabird because of its predilection for papaya fruit. It is found on all the main islands, being abundant in both residential and rural areas, in wet and dry regions, and in high ranch country and forest lands of Maui and Hawai'i (Berger, 1985). The birds are roughly 5 1/2 inches long, with the male's forehead, bib, and rump varying from pale yellow to deep rosy-red; lighter brown below with dark streaks. Females and immatures are brownish-gray above, paler below and streaked (Hawaii Audubon Society, 1984).

House Finch, like the Japanese White-eye, is ubiquitous throughout the GRS. They are especially common in the Kapoho and Kamaili Sections. The Hawaii Forest Bird Survey estimates a population of 7,301 birds in the wet forest habitats in the Puna study area (Jacobi, 1985; Scott <u>et</u> <u>al</u>. in press).

o <u>Mammals</u>

Except for the native Hawaiian Hoary Bat or 'Ope'ape'a (<u>Lasiurus</u> <u>cinereus</u> <u>semotus</u>), an endangered species, all the other mammals found within the GRS were introduced by human beings either accidentally or intentionally.

The Hawaiian Hoary Bat can be found primarily on Kaua'i, Maui, and the island of Hawai'i where it occurs principally below 4,000 ft., although van Riper and van Riper (1982) have observed bats as high as 7,800 ft. on Mauna Kea and 6,000 ft. on Mauna Loa. The Hawaiian Hoary Bat roosts singly in trees. It has been observed in introduced trees such as macadamia nut and kiawe as well as native trees (Tomich, 1969; Kramer, 1971; van Riper and van Riper, 1982).

The species probably occurs throughout the GRS, preferentially foraging in forest openings, along forest edges, or over bodies of water. One bat was sighted during the biological survey of the nearby Kahauale'a lands. Unfortunately, the nocturnal habits of this species makes detection and observation difficult.

Among the non-native mammals which have been reported from the GRS are feral pig (Sus scrofa) and feral cattle (Bos taurus), especially in the forests of the Kilauea Middle East Rift subzone. In the Kapoho and Kamaili Sections feral cat (Felis catus) and infrequently feral dog (Canis familiaris) can be encountered. Four species of rodents occur within the GRS, especially the Kapoho and Kamaili Sections. Evidence of rodent damage to ripe, fallen papaya fruit has been observed by Kjargaard (in Char and Kjargaard, 1984). The House Mouse (Mus musculus), the Pacific Rat (Rattus exulans), and Roof Rat (Rattus rattus) occur in agricultural areas as well as scrublands and along margins of forested areas. The Norway Rat (Rattus norvegicus) has been recorded near human habitations or other structures (Kramer, 1971). The mongoose (Herpestes auropunctatus) was seen and heard in all agricultural areas, especially old overgrown weedy fields, by Kjargaard (In Char and Kjargaard, 1984).

2.0 Invertebrates

Unfortunately, inventories of the invertebrate resources have not been included in the biological studies conducted for the various EISs and EAs for geothermal projects. Literature on these resources is scattered in various taxonomic treatments (Sharp 1899-1913; Cooke, 1921; Caum, 1928; Zimmerman, 1948 et seq; Cooke and Kondo, 1960).

Limited field surveys have been conducted in the areas adjacent to the Kilauea Middle East Rift GRS. The areas surveyed support similar forest types and habitats as those found in the Kilauea Middle East Rift GRS. A fairly rich complement of native invertebrates, including relatively diverse arthropod communities, can be expected in the less disturbed vegetation types within the GRS.

Even in areas subject to frequent volcanic gassing there may be a generally rich component of native invertebrates (S. Gon III, personal communication). Indicator taxa which may be expected in intact native vegetation are presented in Table 5.2.

Non-native invertebrates include ants, Vespula (yellow-jacket wasps), slugs, Oxychilus (garlic snails), as well as a good complement of other non-native insects, spiders, centipedes, crustacea and snails.

Lava tubes may support cave invertebrates (some of which are candidates for endangered status). The Hawaiian aeolian ecosystems on recent lava flows are poorly understood and have only recently been studied in detail, but these are invertebrate

Table 5.2 INVERTEBRATES WHICH MAY BE EXPECTED IN NATIVE VEGETATION

Native Spiders:	Vernacular
Theridion grallator	Hawaiian Happy-face spider
Theridiid spp.	cobweb spiders
Salticid spp.	jumping spiders
Tetragnathid spp.	4-fanged orb spiders
Thomisid spp.	crab spiders
Native Insects:	**Vernacular**
Lispocephala spp.	predatory muscid flies
Dolichopodid spp.	NA
Drosophilid spp.	Hawaiian pomace flies
Tipulidae spp.	Hawaiian crane flies
Microlepidopteran spp.	small-bodied moths
Macrolepidopteran spp.	large-bodied moths
Eupithecia spp.	Hawaiian predatory caterpillars
Collembolan spp.	springtails
(many other species in several orders and families)	
Native Crustacea:	**Vernacular**
Amphipod spp.	NA
Native Snails:	**Vernacular**
Succinid spp.	Hawaiian amber snails
Tornatellinid spp.	Minute land snails

dominated and include several endemic species of Lycosid spiders, flightless crickets, springtails and centipedes that are not represented in surrounding vegetated systems (S. Gon III, personal communication).

On the Kapoho and Kamaili Sections of the Kilauea Lower East Rift GRS, the majority of the vegetation has been disturbed to some degree and introduced species often form the dominant vegetation types. In such areas, native invertebrate diversity is likely to be lower.

Where there are remnant pockets of native vegetation as in pit craters, in cracks and on pu'us, there may be remnant native invertebrates. Surprisingly, even in some 'ohi'a forests where the understory has been severely disturbed, S. Gon (personal communication) has found an assortment of native arthropods in the forest canopy above.

The barren lava flows in the Kapoho Section may still support a native aeolian system in places, but non-native invertebrates, especially ants, may have displaced them.

D. IMPACTS AND MITIGATION

Major concerns or risks to the biota associated with geothermal development and mitigation measures have been discussed primarily in the Puna Geothermal Area Biotic Assessment (Char and Lamoureux, 1985a), the Revised Environmental Impact Statement for Kahauale'a Geothermal Project (Towill, 1982a) and Kilauea Middle East Rift Zone projects (Char and Lamoureux, 1985b and Lamoureux, et al., 1988).

Forests dominated by native species are of special concern. Such forests are more likely to provide refuge for threatened and endangered plants and animals. Disturbance could cause invasion by introduced plants which may affect structural and compositional changes in a forest, thus decreasing its quality as a suitable habitat for native biota. In some cases, impacts can be lessened by siting of geothermal facilities away from sensitive native plant communities and animal habitat. Siting on barren lava flows, areas of stand-level dieback and areas dominated by introduced plants is preferred.

While general data can be provided from Char and Lamoureux (1985a) and the U.S. Fish and Wildlife Service survey of Puna (Jacobi, 1985), intensive, on-site inspection to determine the presence or absence of threatened and endangered species as well as forest quality is required for each site, including access roads. Site specific mitigation measures addressing environmental concerns then need to be presented. Monitoring of each specific site should begin during the initial exploration phase before development commences and continued during the construction and operational phases.

Probable environmental impacts on biota and mitigation measures include:

Direct loss of habitat and destruction of native plant communities as a result of land clearing for geothermal facilities. Siting of roads and well pads during the exploration phase, as well as transmission lines, power plants and other facilities during the later construction and operational phases, on less sensitive areas such as recent lava flows and in areas dominated by introduced species can lessen the impact on the native biota. The general distribution of these sensitive biological areas has been identified and mapped in Char and Lamoureux (1985b) and is presented in Figures V-1, V-1, and V-3. Highly sensitive areas which are dominated by native species such as the 'ohi'a-a(1) and 'ohi'a-a(2) forests should be avoided as much as possible. Early on, the biologists should be working closely with the engineers and planners in identifying and evaluating potential alignment corridors and drilling sites. When road alignments and drilling sites have been selected and staked out, the biologists should conduct a survey on and adjacent to these areas. Realignment and relocation of drilling sites are recommended if threatened or endangered species or sensitive native plants and animal communities are encountered

Invasion of cleared areas by weedy, introduced species. Disturbed sites such as unpaved road margins and open roadsides are prime sites for weed establishment. From such areas, the weedy species move out into small openings in the forest, occupying space once utilized by native species. Invasion by introduced plants also reduces the habitat quality for native birds and invertebrates thus affecting the distribution of these organisms. Clidemia hirta, a State-declared noxious weed, has already been recorded from several localities in Puna, including the Kilauea Middle East Rift Zone GRS at about 1,900 ft. elevation in 'ohi'a-a(2) forest and is of special concern.

Mitigation measures are crucial in areas where geothermal facilities would impact or lie adjacent to 'ohi'a-a(1) and 'ohi'a-a(2) forests; these are found largely in the Kilauea Middle East Rift Zone GRS. Among the recommendations for minimizing spread of invasive weedy species are:

- o limiting vegetation removal to only that which is essential. As little disturbance as possible beyond the edges of roads, drilling sites, and other geothermal facilities should be emphasized. If possible, all transmission lines should be constructed along existing road corridors to minimize the amount of vegetation removed.

- o using soil and rocks from high points in the project area for additional surface or fill material rather than bulldozing them into ridges at the sides of roads or hauling in fill material from outside of the project areas.

- o continual monitoring of developed areas for weeds and appropriate and environmentally compatible methods of weed control for these areas.

- o revegetation with native material as soon as possible. Lamoureux, et al. (1988) noted that weedy species in general require high light intensities to grow well. Quickly revegetating disturbed areas with native species would provide shade thus reducing weed populations. The top foot or two of tree ferns, common in the forested areas, could be retained and replanted on disturbed areas. Removing as few trees as possible during construction will also keep the area shaded.

Long-term effects on biota during operational phase. Air emissions and noise from day-to-day operations are the primary concerns when discussing long-term effects. The principal mitigation measures include effective abatement systems and design features that can be incorporated into the production and energy conversion systems. Air emissions are controlled to meet federal and state standards designed primarily on the basis of human health requirements. Thus far, monitoring of the flora and fauna around the HGP-A site, in commercial operation since February 1982, has not revealed any significant impact to the biological resources from geothermal emissions (Dames & Moore, 1989). However, geothermal plants vary in kinds and quantities of substances emitted from site to site. Periodic environmental monitoring of these sites will be necessary so that cumulative effects of geothermal development activities on the biota can be identified fairly early on.

Venting of a well for short periods could disrupt the native avifauna. Relatively high noise levels would occur within a one-mile radius of a well during venting. If endangered species such as 'I'o are known to be present nearby, mitigation measures should include that such activities be conducted during the non-breeding season of the particular species.

Compaction of soils associated with construction, as well as standing water in abandoned machinery and used materials associated with operation activities, may provide breeding sites for mosquitoes that are vectors of certain avian diseases. All sites should be periodically checked to see that drainage remains unimpeded, particularly in areas with high native bird populations.

During preparation of this section, some areas of need became evident. While there is good biological data available on the plants and vertebrate animals of the GRS and Puna area, information on the native invertebrate resources is lacking. Future biological surveys should include invertebrate studies, especially in areas containing more or less intact native forests.

There is also a need for enforcement and follow up of mitigative measures or recommendations agreed upon by the geothermal developers and the permitting government agencies. The DLNR oversees these activities in conservation zoned lands but often staff and funding are inadequate or lacking. One solution which has been suggested (N. Ho, personal communication) would be for the geothermal developer to set aside funding for follow up monitoring of recommendations. The funds could be used by DLNR or a community organization which would report directly to DLNR.

PART VI: CULTURAL RESOURCES

This review presents the results of a search of archaeological and historical literature for the purpose of assessing possible archaeological impacts of geothermal development of three geothermal resource subzones in the Puna District. The sources consulted include previous archaeological reports within and adjacent to the areas, as well as maps and historical references of the post-European Contact Period. Figures VI-1, VI-2 and VI-3 show known site areas within all three of the geothermal resource subzones.

In addition, a botanical study of the area prepared by the University of Hawaii and maps of dated lava flows prepared by Ms. Tina Neal of the U.S. Geological Survey proved very useful. Figures VI-4, VI-5 and VI-6 show recent lava flows within the subzones.

A. HISTORICAL REVIEW

Traditional Accounts

Puna was one of the six ancient districts or moku of the Island of Hawai'i. Traditional accounts relate that Puna was a rich agricultural region, a center of development for religion, and focus for myths concerning Pele.

Traditional references to Puna agriculture, like the legend of Keliikuku in W.D. Westervelt's Hawaiian Legends of Volcanos (1916), and Samuel Kamakau's writings on Imakakoloa in Ruling Chiefs (1961) imply an abundant supply of a wide variety of agricultural goods. "My country is charming. Abundance is found there. Rich, sandy plains are there, where everything grows wonderfully," (a boast of Keliikuku) (Westervelt, 1916). Imakakoloa, a great chief in the district of Puna at the time of Kalani'opu'u (ca 1770) was resisting the "extravagant demands for contributions of all kinds of property" to Kalani'opu'u (D. Barrere, 1959 In Emory, 1959). "It was I-maka-koloa, a chief of Puna, who rebelled, I-maka-koloa the choice young 'awa (favorite son) of Puna. He seized the valuable products of his district, which consisted of hogs, gray tapa cloth ('eleuli), tapas made of mamaki bark, fine mats made of young pandanus blossoms (ahu hinalo), mats made of young pandanus leaves ('ahuao), and feathers of the o'o and mamo birds of Puna" (Kamakau, 1961). Though these references are non specific they are suggestive of the traditional Hawaiian agricultural practice of using a wide

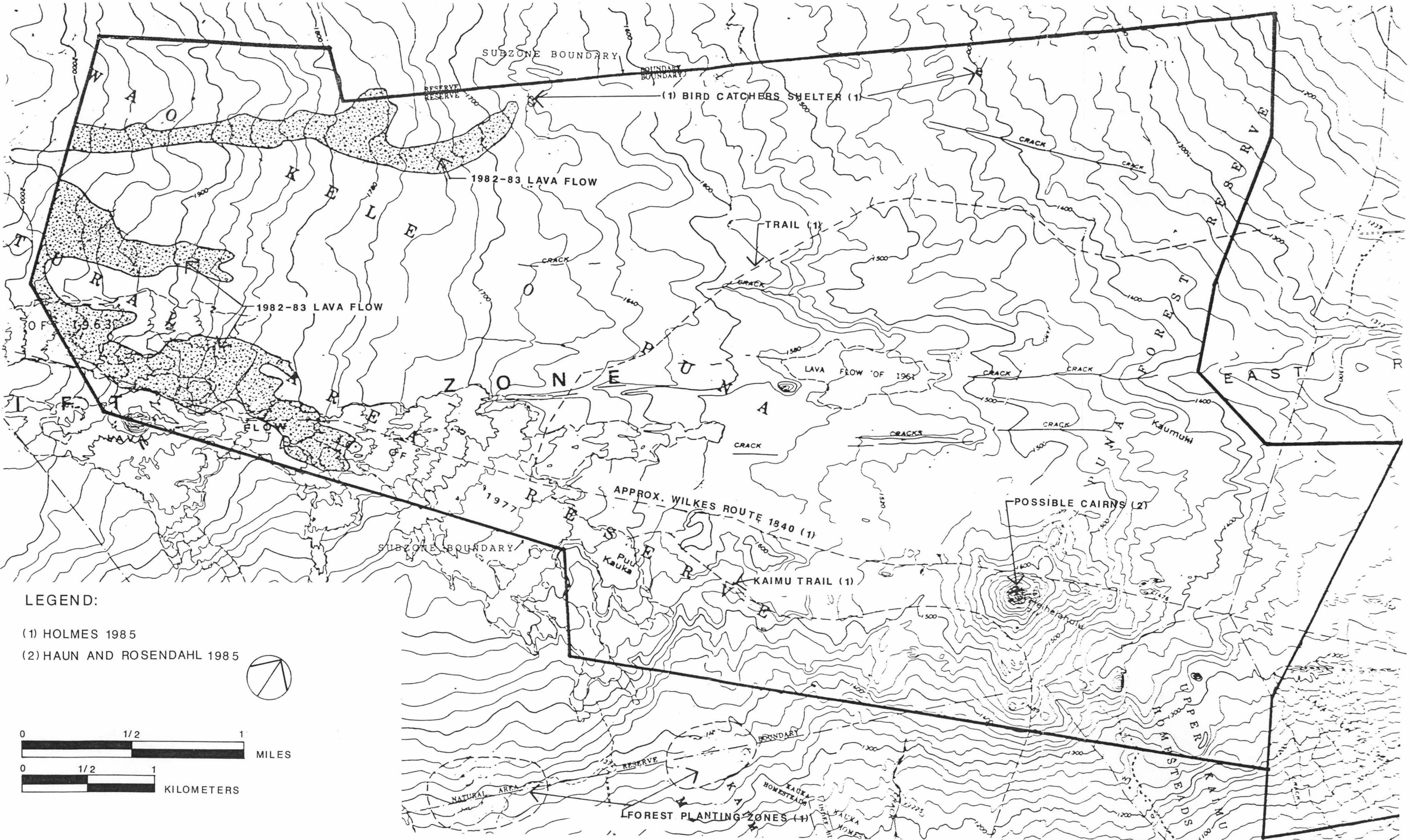


Figure VI-1

KILAUEA MIDDLE EAST RIFT SUBZONE SHOWING KNOWN AND POTENTIAL SITES

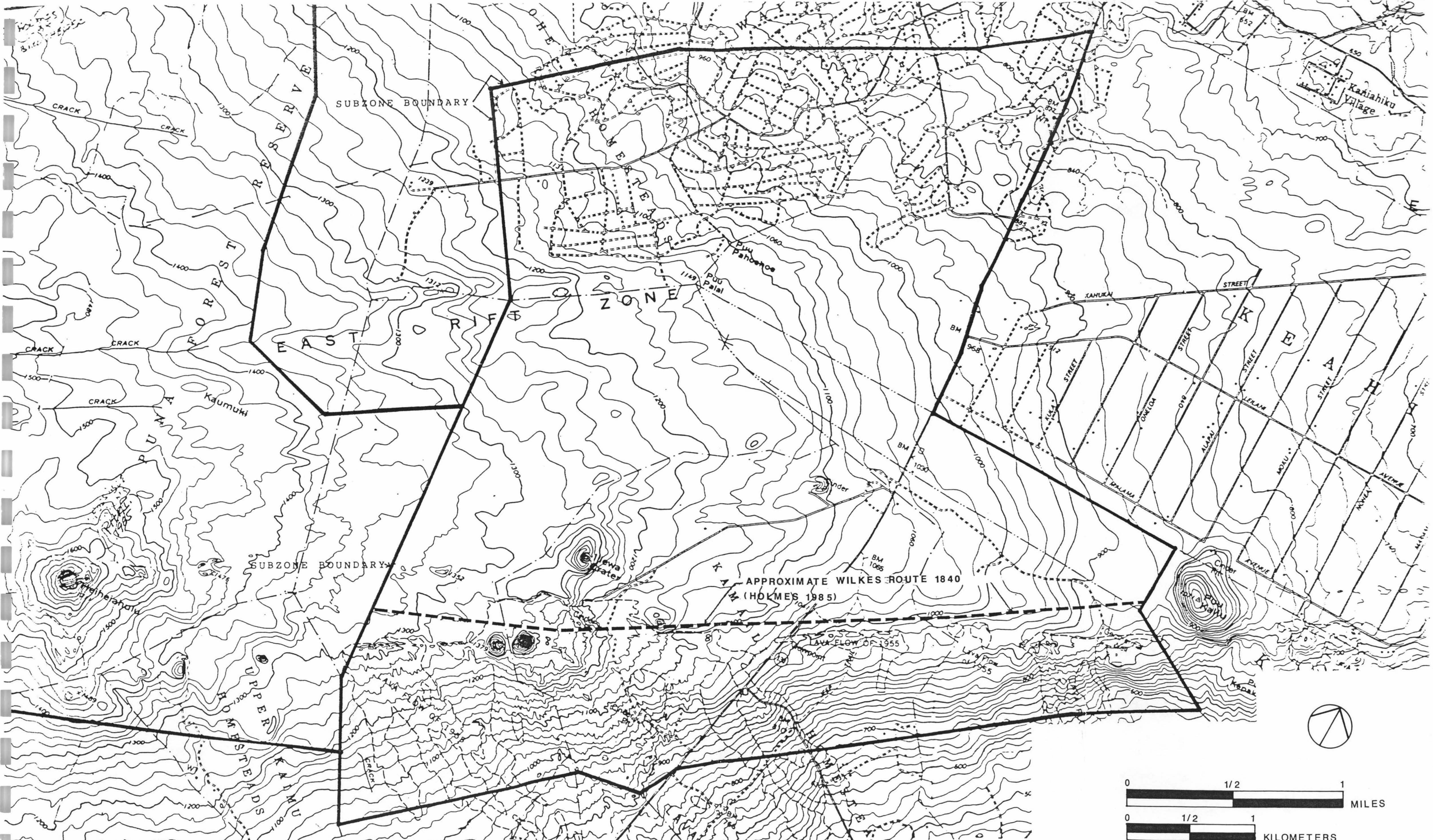


Figure VI-2
KAMAILI SUBZONE SHOWING KNOWN AND POTENTIAL SITE AREAS

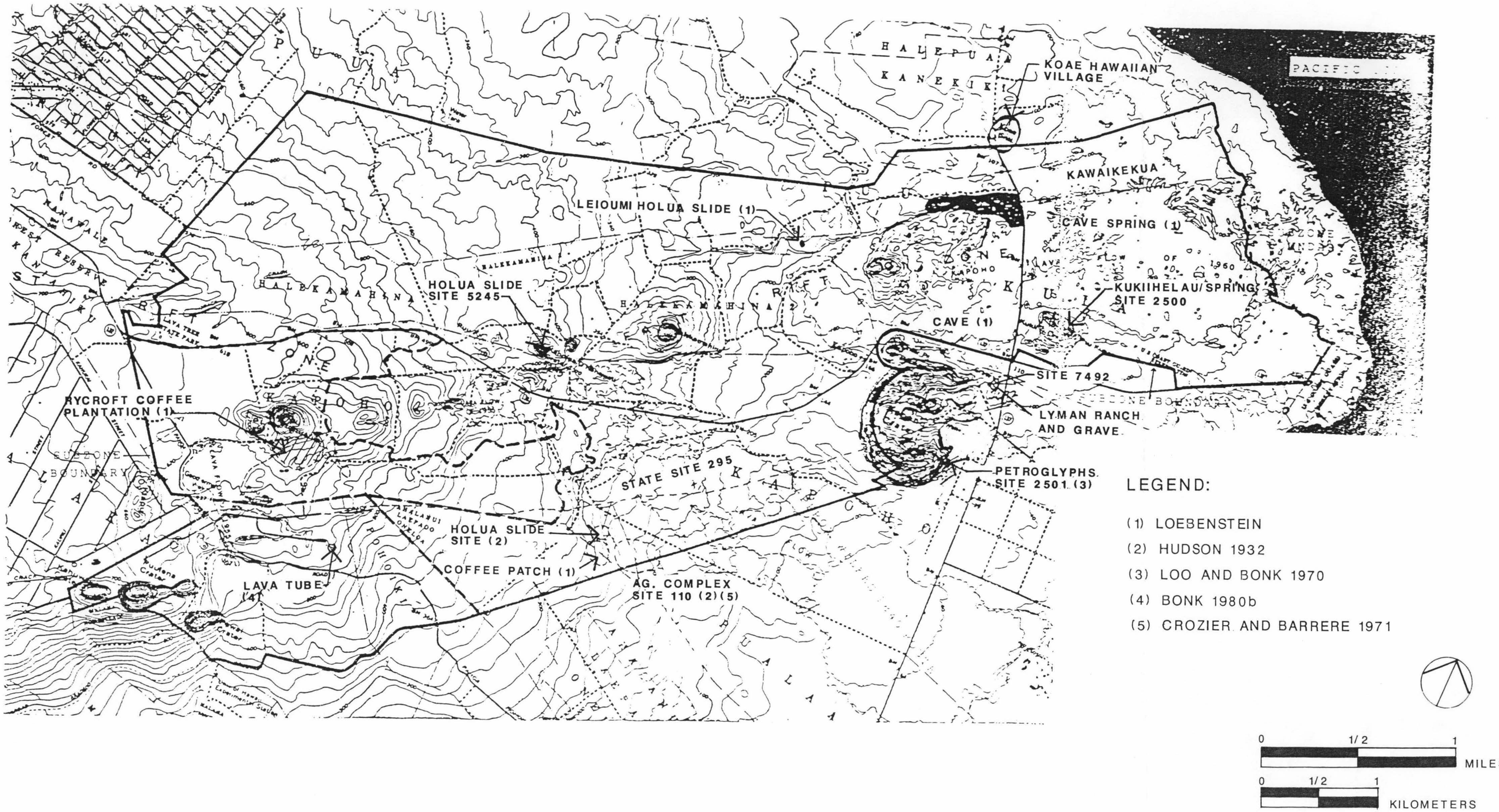


Figure VI-3
KAPOHO SUBZONE SHOWING KNOWN AND POTENTIAL SITE AREAS

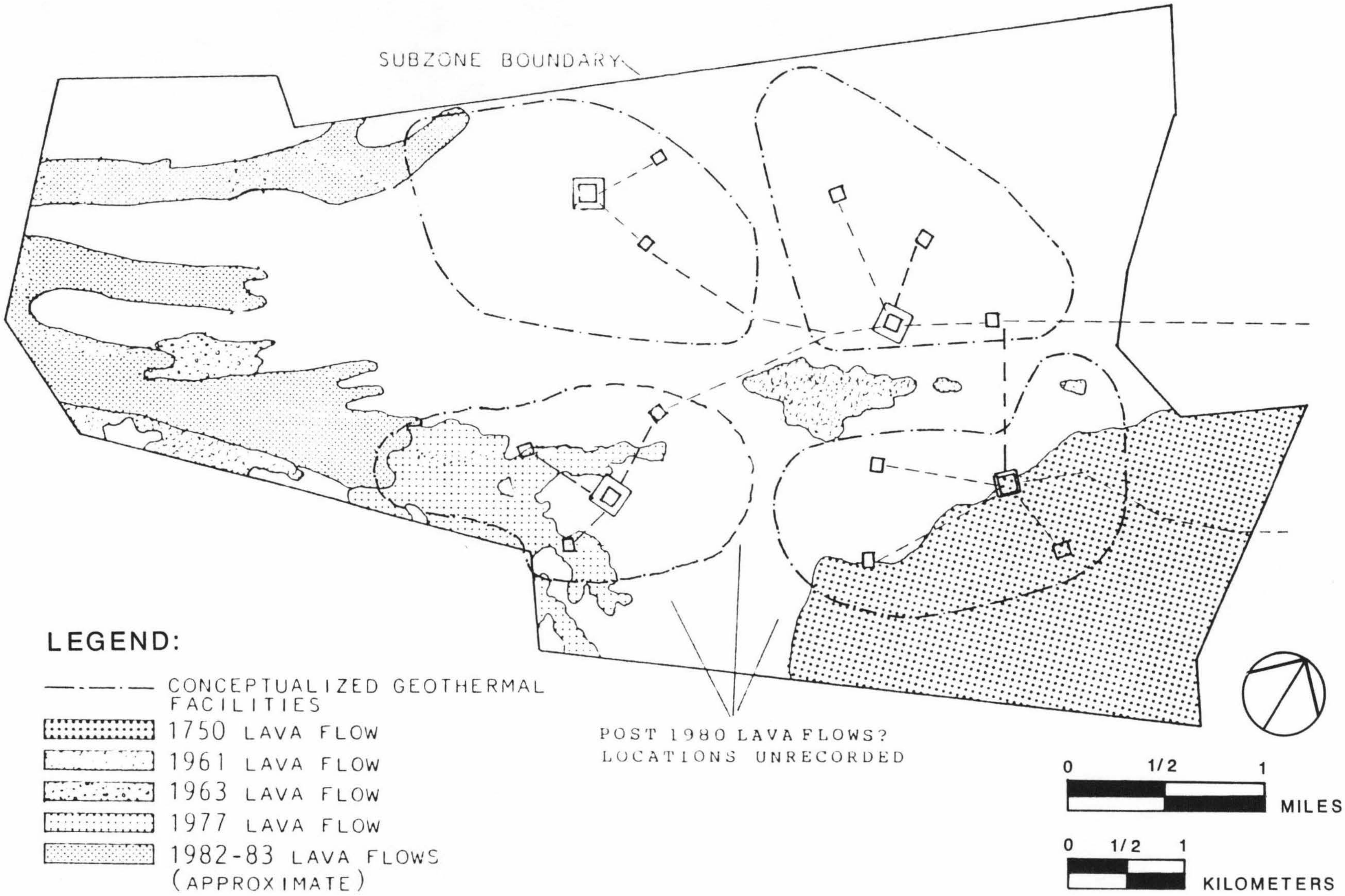


Figure VI-4

KILAUEA MIDDLE EAST RIFT SUBZONE SHOWING LAVA FLOWS YOUNGER THAN A.D. 1800

SOURCE: HOLCOMB, USGS, 1980.

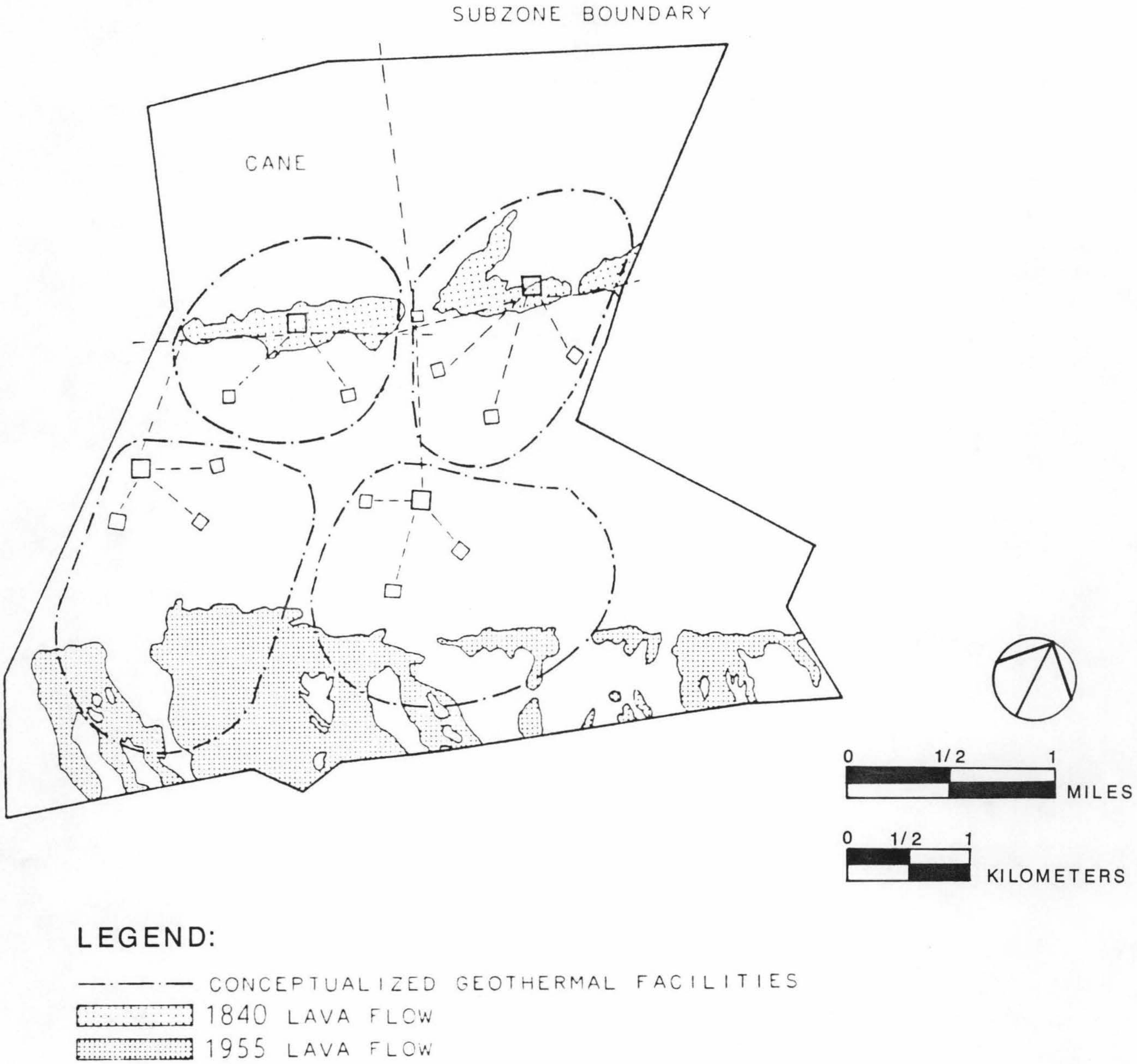


Figure VI-5

KAMAILI SUBZONE SHOWING LAVA FLOWS YOUNGER THAN A.D. 1800

SOURCE: HOLCOMB, USGS, 1980.

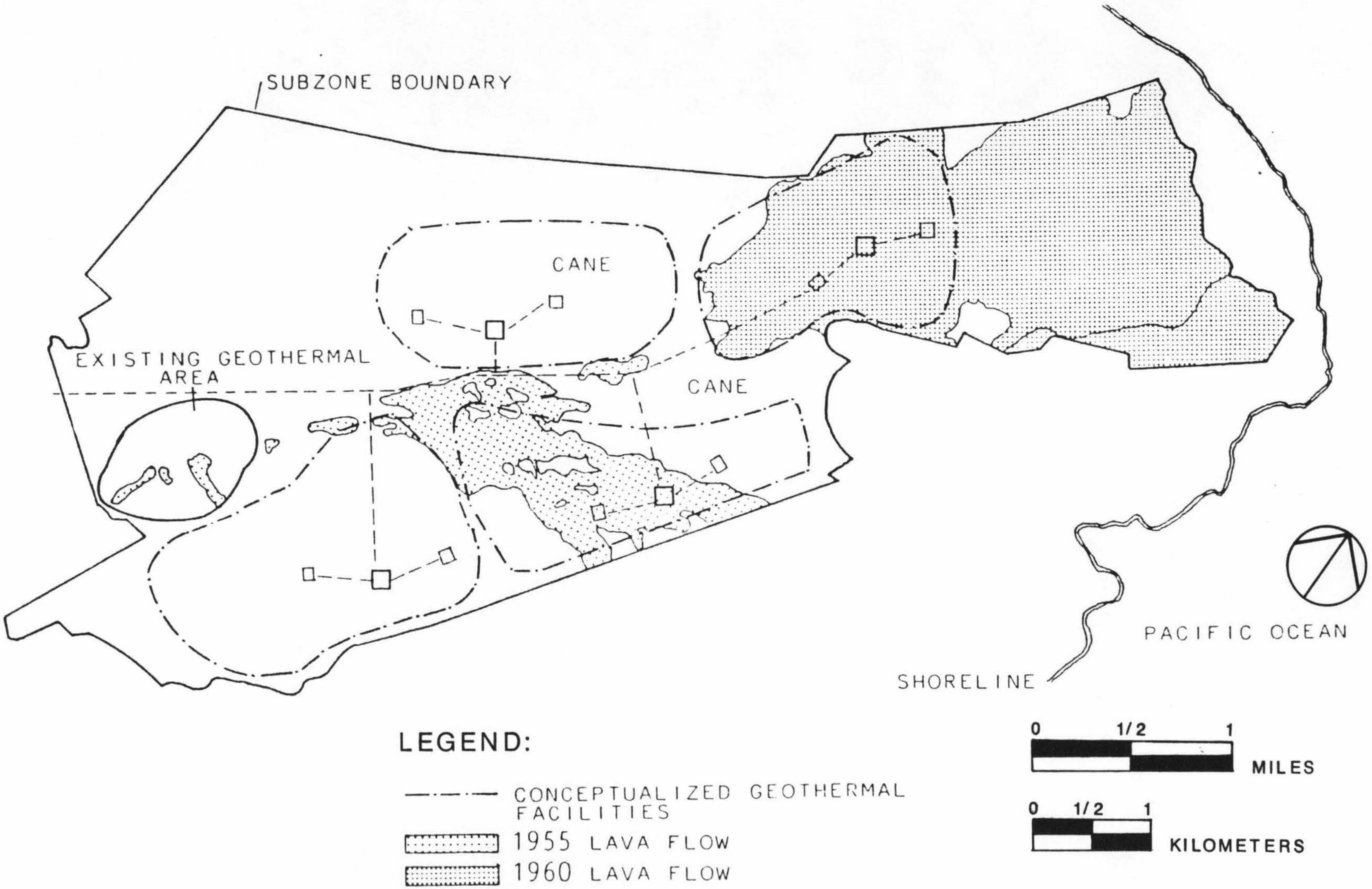


Figure VI-6

KAPOHO SUBZONE SHOWING LAVA FLOWS YOUNGER THAN A.D. 1800

SOURCE: HOLCOMB, USGS, 1980.

range of environmental zones. These would include the coastal zone, the immediate upland agricultural zone or "the sandy plains where everything grows wonderfully" and the forest zone for such goods as mamaki bark for tapa and the valuable bird feathers for capes (etc.). E.S.C. Handy wrote of Puna saying, "One of the most interesting things about Puna is that Hawaiians believe, and their traditions imply that this was once Hawai'i's richest agricultural region and that it is only in relatively recent time that volcanic eruption has destroyed much of its best land" (Handy and Handy, 1972).

The references to Puna as a center of religious development has to do with Waha'ula Heiau (Volcanoes National Park). Waha'ula is believed to be the first heiau built by Paao "a priest from Tahiti," around A.D. 1275 (Loo and Bonk, 1970). Paao established a "line of priesthood" that lasted till after the death of Kamehameha I (Beckwith, 1979). Waha'ula, a "Luakini" class heiau is also known as the last temple in Hawai'i to have had the practice of human sacrifice performed within its walls (Loo and Bonk, 1970). Another major heiau in Puna with a long history is Kukii Heiau (St. Site 2500). Kukii Heiau is located on the top of Kukii Cinder Cone within the proposed geothermal subzone, Kapoho section. Kukii Heiau, according to traditional accounts was built "by Umi (ca ad 1500), a devoutly religious ruler of the island of Hawai'i, after he had taken control of the island....

Kukii was constructed of dressed and hewn stone..." (Fornander, 1969), a technique rare in pre-European Hawai'i. Though Kukii Heiau has been heavily disturbed by natural events and stone removals, its location within the project area must be noted.

Legends

There are numerous legends concerning Pele and the district of Puna. They generally relate how Pele's anger is characterized by lava covering specific and/or large tracts of land. For example, in the aforementioned legend of Keliikuku, who boasted of his (Puna's) country's abundance, comes home (from O'ahu) to find "his vertical plains covered with black lava ... and the remnants of the forest still burning (Westervelt, 1916). One of several legends concerning Cape Kumukahi and Pele has to do with the formation of the point or cape. Kumukahi was a chief in Puna. He was a handsome man who loved the ancient games. He pleased Pele, but when she came to him as an old woman demanding to join the games he ridiculed her. She chased him to the sea, covering him with lava, forming the cape called Kumukahi (Westervelt, 1916).

The sheer volume of traditional accounts relating Pele to Puna is undoubtedly due to the very active volcanism of the area. The overriding theme of these accounts is the power of Pele to transform the landscape. Pele is mentioned in relation to the many cinder cones, formation of Cape Kumukahi, unusual lava formations, and the covering or destroying of large tracts of land.

Early History

Though Puna was a rich agricultural region, and the site of Paau's first heiau (Waha'ula) it appears not to have been politically strong during traditional times. Dorothy B. Barrere in "Political History of Puna" states: "We find that Puna, as a political unit played an insignificant part in shaping the course of the history of Hawai'i Island. Unlike the other districts of Hawai'i, no great family arose upon whose support one or another chiefs seeking power had to depend for his success. Puna lands were desirable, and were eagerly sought, but their control did not rest upon the conquering of Puna itself, but rather upon control of the adjacent districts; Ka'u and Hilo" (Barrere, 1959 in Emory, 1959).

The review of literature pertaining to the traditional or pre AD 1796 Puna District seemingly indicate a dichotomy of sorts. The Puna District was described as, "once Hawai'i's richest agricultural region" (Handy and Handy, 1972), and a center for religious development with the construction of Waha'ula Heiau (ca AD 1275) and establishment of a line of priesthood by Paao.

Post Contact Period

The historic period (post AD 1776) as it concerns Puna, is characterized as it is throughout Hawai'i by a decline in population, abandonment of traditional villages and agricultural sites, and the move to a market based society.

The early European descriptions of the Puna area generally recount that there was abundant and a wide variety of agricultural lands from different environmental zones. The population was clustered along the shoreline in "villages".

Early descriptions by the Rev. Ellis (1833), Rev. Titus Coan (1835), and the Wilkes Expedition of 1841 are the most revealing. In August of 1823 the Rev. Ellis passed through the Puna district and wrote: "The country had been much more populous than any we had passed since leaving Kona" (Ellis, 1963). The Rev. Ellis estimated that in the "vicinity of the village of Kaiau" the population was probably around 2,000. Ellis and his fellow preachers, Artemis Bishop and Asa Thurston continued on to Hilo, stopping and giving sermons at villages like Kehena and Opihikao which he also called populous. Ellis also mentioned agricultural products such as taro, sweet potatoes and sugar cane cultivated along the coastal strip and breadfruit "in a high state of cultivation" inside Kapoho Crater (Barrera and Barrere, 1971).

The Rev. Titus Coan came to the Hilo Mission Station in 1835 and became the "district's" (includes Puna) appointed preacher. Titus Coan was a major force in the Puna area for nearly 50 years. He was the prime mover of a great religious revival that lasted from 1837 to around 1840. The revival was centered at Hilo and accelerated the "permanent or temporary abandonment of entire villages in outlying areas" (McEldowney, 1979). During Coan's tenure he made numerous field trips to preach and in 1841 made a census for Puna. Coan noted that most of the inhabitants of Puna lived along the shore, though hundreds lived inland and the population was 4,371 of which none were foreigners (Holmes, 1985, from Missionary Herald extracts). In 1846 Chester Lyman, a professor from Yale, accompanied Coan on a tour of Puna and observed scattered agricultural activity in the upland forest, the breadfruit trees and taro patches in Kapoho Crater, and melons and gourds at Koae (Lyman, 1924).

The Wilkes Expedition (1840-1841) follows the Kilauea East Rift Zone from Kilauea to Kapoho Crater then on back to Hilo. The descriptions again generally recount earlier descriptions. The expedition did encounter an "extensive upland taro patch" which Tommy Holmes approximated to be between 2,000 and 2,200' elevation within the <u>ahupua'a</u> of Kahauale'a (i.e. west of the project area). Wilkes commented on the sweet potatoes "growing among heaps of stones and pieces of lava" (Wilkes, 1845) and also observed the banana, taro, and breadfruit growing in Kapoho Crater.

The mid-1800s (1840-1860) were a time of major change for all of Hawai'i including Puna. Though subsistence agriculture still dominated life in Puna, it was on a much reduced scale. The measles epidemic of 1848 began in Hilo and spread throughout the island, killing an estimated one-third of the population (McEldowney, 1979). This was followed by the smallpox epidemic of 1853 with a further reduction of population.

The disruption of life styles due to the epidemics was coupled with an economy increasingly based on foreign trade, to whalers and California Gold Rush population explosion. Also the traditional land tenure policies changed with the "Great Mahele" (1840s-1850s) which allowed for private ownership of land.

In all of Puna there were only two small kuleana (lots to the actual persons living and working the land) awarded which is very unusual. Instead, the "sons and heirs of Kamehameha I's supporters became actual owners of the lands given to their fathers in recognition of the services to him". There were eleven ali'i who received title to virtually all of Puna as "absentee owners". By the end of the 1850s "in most back country ahupua'a the old subsistence-level life style was no more" (Crozier and Barrere, 1971).

The Nineteenth Century

The late 1800s saw the beginnings of large-scale commercial ventures in Puna. Cattle ranching became formalized with the Shipmans and Eldarts leasing portions of Puna from Keeau to Pu'ala'a in 1878. By 1890 W. H. Shipman controlled most of the grazing lands of Puna. In the 1890s coffee was grown and milled by R. Rycroft and was shipped out of Pohoiki. The "Lyman Ranch" near Kapoho Crater and the "Coffee Plantation" and mill of Rycroft are both located on the 1895 Loebenstein map.

The most important commercial venture began in 1899 with the incorporation of 'ola'a Sugar Plantation, the first in Puna (Kelly, et al., 1981). In 1900 the Puna Sugar Company was established but was essentially run as a subsidiary of 'ola'a Plantation from 1905 to 1936 when 'ola'a bought Puna Sugar Co. The Puna Sugar Co. eventually had some 6,500 acres in and around Kapoho.

In conjunction with the sugar industry, were rock and lumber industries which were all tied in with the expansion of the railroad into Puna. The railroad began in 1899 as the Hilo Railroad Company with Benjamin F. Dillingham and Lorrin A. Thurston as the original promoters. The railroad first hauled ohia logs from the forest clearing for the cane fields. In 1901 the rail line was extended into Kapoho with a 5-mile branch to Pahoa.

The Hawaiian Mahogany Lumber Company was started in 1907 with a mill in Pahoa. The company had gotten a contract with the Santa Fe Railway System to supply Ohia wood ties. In 1910 the lumber company "secured the right to lumber the forest on a tract of unleased government forest land in Puna, adjoining the Kaohe Homesteads at Pahoa, and having an approximate area of 12,000 acres" (Conde and Best, 1973). The company, later known as the Hawaii Hardwood Company, went out of business around 1918.

Rock quarrying at Kapoho was conducted from 1908 to 1925 with rocks hauled on the Hilo Railroad Company lines. The bulk of the quarried rocks were utilized in the construction of the

Hilo breakwater. The Kapoho quarries delivered some 88,657 tons of rock for the breakwater from 1922 to 1925 (Kelly, et al., 1981).

Sugar remained the single most important economic factor in Puna with much of the Kamaili and Kapoho sections under cultivation. In 1922 there were some 2,000 acres in the Kapoho area under cultivation. The Puna Sugar Co. operations continued to expand adding more acreage to cane cultivation. However, the 1955 Kapoho eruption was said to have eliminated some 1,400 acres of cane area. In 1979 Puna Sugar Co. harvested nearly 7,000 acres of cane out of their 16,000 acre total (Kelly, et al., 1981).

The Kilauea Middle East Rift Zone subzone (Figure VI-1)

The review of historical literature indicates that the Kilauea Middle East Rift Geothermal Subzone (approximately 9,000 acres) as a portion of the Puna Natural Area Reserve was not used extensively during prehistoric or historic times. During prehistoric times there were probably forest planting areas, specifically on the southern fringe. The forest was exploited for such things as wood, bird feathers, tree bark for tapa, and olona for cordage. This forest area or wao (upland jungle) would also have been an important food resource area for such items as wild taro and bananas during times of famine. During historic times olona was still being extracted from the forest area until the late 1800s. In the early part of the 20th Century commercial logging of Ohia was undertaken in conjunction with the beginning of the sugar industry and its railway system. The area became a forest reserve starting in 1911 with 19,850 acres and was expanded upon to 25,738 acres in 1928. In 1981 a portion of the reserve, 16,847 acres was given Natural Area Reserve status (Holmes, 1985).

Kamaili Subzone (Figure VI-2)

The Kamaili subzone section (approximately 5,500 acres) appears to have been only marginally used for agriculture during prehistoric times, but more than the Puna Reserve area. No specific references to this area were found but general remarks by early historic visitors indicate that at least the southern and northern fringes were somewhat utilized as "upland planting areas." Historically there has been extensive sugar cane cultivation, especially in the northern portion, excepting the central area which is rocky lava lands.

The Kapoho Subzone (Figure VI-3)

The Kapoho subzone section (approximately 7,300 acres) was, of the three subzones, the most intensively utilized during the prehistoric and historic times. One of the major differences is that the Kapoho section extends to the coast (near Cape Kumukahi) and the entire southern boundary is also considerably closer to the coast than the other two geothermal subzones.

Evidence of prehistoric land use include an agricultural complex and destroyed <u>holua</u> slide in Upper pu'ala'a <u>ahupua'a</u> (Hudson Sites 109, 110, St. Site 4295), Petroglyphs at Kapoho Crater (St. Site 2501) and Kukii Heiau (St. Site 2500). Traditional and early historic accounts are also indicative of prehistoric usage. These include references to Kaholua O Kahawali (St. Site 5245), a cinder cone in a Pele legend, utilized as a <u>holua</u> slide, the formation of Cape Kumukahi as related in another Pele legend. The early historical accounts include references by Wm. Ellis, Titus Coan, Wilkes, and Chester Lyman to the populous shoreline habitation and agricultural zone with extensive upland agricultural areas. These references include specific mention of the "plantation" within Kapoho Crater and Koae Village and though both are just outside the project area (abutting the southern and northern boundaries respectively) their location is suggestive of similar land usage within the project area. The 1895 Loebenstein map also shows "ancient cultivating grounds" in Upper Pu'ala'a and near Pu'uhonua'ula "kalo" is referenced further evidence of the agricultural usage of the Kapoho section.

During historic times the area came under increasing pressure by wide-scale commercial activities. This began with cattle ranching in the 1870s and included the short lived coffee industry in the 1890s. The greatest and longest lasting venture was the sugar industry which began around 1900. The sugar industry also was a catalyst for the railroad system, lumbering, and rock quarrying. The Kapoho area eventually had well over 2,000 acres in cane cultivation under the Puna Sugar Co. However, the eruptions of 1955 and 1960 took over a large portion of this acreage.

B. ARCHAEOLOGICAL REVIEW

Introduction

Archaeological research, concerning Puna in general, was first initiated in the early 1900s. These early investigations (Stokes, 1919, Thrum, 1907a) were almost exclusively concerned with major stone structures (i.e. heiau). In the 1930s A.E. Hudson conducted a more comprehensive archaeological survey which involved mostly coastal areas from Waipi'o Valley (Hamakua) to Punalu'u (Ka'u). In the 40s and 50s K.P. Emory and other Bishop Museum staff members conducted surveys in two different Puna locations. Emory, in 1945 conducted an exploration of "Shipman's Cave" in Keaau, Puna. In 1959 the Bishop Museum did research on the "Kalapana Extension of Hawai'i Volcanoes National park" which included a section of the "Political History of Puna" by Dorothy Barrere. The 1960s through 1980s saw the advent of contract archaeology which has produced numerous reports concerning the Puna area.

The Three Major Occupation Zones

The majority of research has been conducted along the coast, but a few reports have dealt with inland areas also. The general pattern that has emerged from the archaeological research indicates that the highest concentration of sites (habitation, religious, and agricultural) occurs within the "coastal zone" areas.

The next highest concentration of sites would be the adjacent "upland agricultural zone." Sites in this zone would include agricultural complexes in suitable arable land and dispersed habitation features.

Beyond the upland agricultural zone would be the "forest zone." The forest zone activities would include procuring of wood products, fibrous materials such as olona for cordage, bird catching for valuable feathers, and foraging for food products, especially during times of famine. The references to habitation features in the forest zone indicate that they would have been of a temporary nature and built out of biodegradable materials (i.e. ti leaves, etc.) leaving virtually no clue of the former locations. Other archaeological features within the forest zone would include trails and associated features (i.e. ahu) and possibly burials associated with cinder cones.

One type of sites that could be found in any of these "zones" is the lava tube. There have been a number of major tube systems, as well as isolated lava tubes, found throughout the Puna area. Tubes have been utilized for everything from temporary habitation features to refuge and religious sites (including burials and heiau).

The zones referred to form the general pattern of traditional Hawaiian land use (coastal, upland agricultural, and forest), as indicated by archaeological investigations are variable in nature. The zones have been variously described in terms of elevation, distance from the shoreline, and vegetation. Holly McEldowney (1979) presented a settlement pattern "based on analysis of archaeological data...and literature from the early historic period" concerning the area from Cape Kumukahi to Hilo in which she describes five zones (I -V in terms of elevation). These included the Coastal Zone I (0-50 ft.), II Upland Agriculture (50-1,500 ft.), III Lower Forest (1,500 - 2,500 ft.), IV Rain Forest (2,500 - 5,500 ft.), V Sub-Alpine (5,500 - 9,500+ ft.). Clearly, the elevations of the zones are dependent on the variability in physiography of the specific study area(s). However, the conclusions by McEldowney concerning these zones are that "Substantial pre-historic-type settlements were found to have occurred on the coast, with extensive agricultural fields located in areas of Zone II. The higher elevation areas of Zones III, IV, and V were utilized for exploitation of a large variety of forest resources, such as trees, fiber, birds, etc. and trails" (Komori and Peterson, 1987; McEldowney, 1979).

A similar settlement pattern has been noted in other archaeological reports pertaining to Puna though in some cases the zones are referred to in distance from the shore line (i.e. 0-1 mi, coastal zone, etc.). Crozier and Barrere (1971) characterize the coastal zone in Pu'ala'a, Puna as follows: "From the standpoint of sheer number of archaeological features in a relatively small areas, this is a very important archaeological zone...it is safe to assume that this coastal section was fairly important before European contact". This same report also included a portion in the upland agricultural zone, where mounds and a "small complex" (agricultural) were located. These upland features are within the southwestern boundary of the Kapoho Subzone Section.

Ross Cordy in a "field check" of the *ahupua'a* of Keauohana observed a similar pattern of a high density of sites near the coast, including a possibly prehistoric cemetery "as impressive a cemetery as I have seen, including the large Kaloko cemetery in North Kona". Cordy also observed agricultural features that became more formalized inland, "These sites (agricultural) are less formal terraces and irregular low-walled areas in the seaward depression. But formal walled plots and perhaps *kuaiwi* walls are present inland". Cordy also mentions that a local informant suggested "that intact remains may well continue inland to the Keauohana Forest Reserve", which would be at the southwestern boundary of the Kamaili subzone section (Cordy, 1987).

The upland agricultural zone has been briefly discussed in relation to Pu'ala'a and Keauohana. Other reports discussing this zone include Yent and Ota (1982) and Komori and Peterson (1987). Yent and Ota as staff members of DLNR "evaluated the archaeological cultural resources of the Halepua'a sections of the Nanawale Forest Reserve in Puna." This reconnaissance located "a remnant of the native agricultural system"...which "consists of mounds and depressions for the planting of such food plants as sweet potato, breadfruit, banana, and possibly taro" (Yent and Ota, 1982). This "remnant" of an agricultural complex is within the 100 to 200 ft. elevation with the authors further stating: "The remnant at Halepua'a is also important in the context of the Kahuwai Village Complex (Site 4278) located just north of Halepua'a. The Kahuwai Village complex site is coastal and includes canoe landing sites and structures while Halepua'a is just mauka and is an example of an agricultural complex. Thus, the two site areas considered together incorporate both marine and agricultural resources being utilized in the traditional Hawaiian pattern for the Puna vicinity" (Yent and Ota, 1982).

There are three recent archaeological reports (Hommon, 1982; Holmes, 1985; Haun and Rosendahl, 1985) concerning the forest zone of Puna. Both the Hommon and Haun and Rosendahl projects included actual reconnaissance surveys in Upper Kahauale'a and the Waokele O Puna Natural Area Reserve respectively. The Holmes report was a "documentary literature search" on the "Puna Forest Reserve/Wao Kele O Puna Natural Area Reserve."

These reports detail the virtual absence of archaeological sites and the low probability of finding sites. Hommon found "only two indications of past human activity", one "evidently an abandoned jeep road," the other "a small (5 by 4 feet or c. 1.5 by 1.2 meters) isolated area of Kahili ginger plant" (Hommon, 1982).

Though the Holmes report did not include on the ground survey, the documentary research indicated that "while there was apparently episodic, and perhaps occasionally even sustained use or activity in the area, such activity apparently did not result in any significant structures/sites. None, at this point, are known" (Holmes, 1985). Haun and Rosendahl's project included ground and aerial (helicopter) reconnaissance. "One site, a cluster of possible prehistoric Hawaiian burial structures, at the summit of (Pu'u) Heiheiaholo (Haun and Rosendahl, 1985) was located (Figure VI-1). No other sites historic or prehistoric were observed in either the ground or aerial surveys.

Though there was a general lack of known or newly located sites all three reports suggest that there should be sites within the forest reserve. However, concerning the existence and probability of locating archaeological sites Rosendahl states: "The negative results support the indication of the previously completed limited ground reconnaissance that most archaeological remains to be found within the project area will probably be relatively sparse in density, tenuous in nature, and difficult to recognize with certainty" (Haun and Rosendahl, 1985).

Archaeological reports concerning lava tubes within the Puna District include: Emory (1945), Ewart and Luscomb (1974), Bonk (1980b), Yent (1983), Olson (1984), and Peterson and Komori (1987). Generally, the lava tubes are not well-documented in either traditional or early historical accounts. The one major exception, as reported by L. Olson, is State Site No. 10001 (Puna Cave Complex) which he correlated to traditional accounts concerning Pele. Lava tubes and tube systems can be found from the coastal zone to the upland forest zone. However, the only confirmed lava tube cave site within the project area is in Bonk (1980b) (Figure VI-3). This cave "formed when a section of an old lava tube collapsed" was not explored by Bonk because of the "20 to 25 foot sharp drop" to the cave floor. The cave is in the Kapoho subzone section in an area of heavy growth of Pandanus and other trees...." However, I noted quite a few ti plants growing around the rim area...and I can easily infer that this cave may well have served a cultural function such as that for burial purposes" (Bonk, 1980b).

Archaeological investigations of lava tubes in Puna and elsewhere, have proven to be quite productive. Though lava tubes have not been well documented within the project area it can be assumed that with more systematic survey coverage lava tubes and/or tube features (i.e. sinks, blisters) will be found.

Summary

In general this archaeological record for Puna has correlated well with traditional and early historic accounts. Higher concentrations of sites (habitation, etc.) and the more impressive structures and complexes are associated with the coastal zone. Immediately inland and up to the forest margin the "upland agricultural zone is dominated by agricultural features that in some places are a formalized system including, "Formal walled plots and perhaps kuaiwi walls" (Cordy, 1987). The forest zone has not been extensively surveyed archaeologically. The work done has found little evidence of prehistoric usage. However, this is somewhat to be expected, according to the early historical accounts of only specialized and sporadic use of the forest zone.

Historical land use is also evident in the archaeological record. The Puna area and particularly portions of the Kamaili and Kapoho subzones have been utilized for sugar cane cultivation. Cane cultivation has been most prevalent in the "upland agricultural zone" and the existence of prehistoric surface sites in these areas is unlikely. The railway bed (Hilo Railroad Co.) associated with cane transportation (pre 1946), is still in existence, in certain locations and portions have been recommended for preservation (Peterson and Komori, 1987).

The archaeological and historical records indicate that the Kapoho Geothermal Subzone section (Figure VI-3) was, of the three geothermal subzones, the most extensively used. The Kapoho section would include both the coastal and upland agricultural zones which were of the greatest importance to the traditional Hawaiian settlement pattern. The Kamaili Geothermal Subzone (Figure VI-2) probably contained prehistoric agricultural sites, especially the northern and southern boundaries, as well as associated habitation, lava tubes and trail sites. The Middle East Rift Zone Geothermal Subzone (Figure VI-1) (Wao Kele O Puna Natural Area Reserve) probably contained very few sites other than temporary shelters, trails, and forest planting areas.

C. SUMMARY IMPACTS AND MITIGATION

Although it is clear from historical records and 19th Century Maps that the upland of Puna within the three Geothermal subzones were utilized by ancient Hawaiians and utilized into the historic era, the actual number of recorded and potential site areas are limited. This could be a result of the lack of systematic survey in the areas and a number of sites may be present, but are as yet undiscovered. However, it is certain that large areas of the lava lands are devoid of archaeological remains, particularly in the more inland sections. Most of the areas that would have been within the upland planting zone have been inundated by recent lava or saw long-term use in sugar cultivation.

<u>The Three Subzones within the Kilauea East Rift Zone</u>

Haun and Rosendahl (1985) recorded some possible cairns in the Kilauea Middle East Rift Subzone at Heiheiahulu (under cane in 1985) and Holmes (1985) recorded a trail (the Kaimu Trail) and some possible bird catching shelters (Figure VI-1). It is probable that portions of the Kaimu Trail have been covered by post-1982 lavas in the south central portion of the subzone. The western portion has been covered by lavas post dating 1961 (Figure VI-4).

Within the Kamaili Section of the Kilauea Lower East Rift Subzone there are no recorded archaeological sites (Figure VI-2) and the southern and north central areas have been covered by the 1955 and 1840 flows respectively (Figure VI-5). The northern portion was planted in sugar cane.

The Kapoho Section of the Kilauea Lower East Rift Subzone contains the largest number of sites or potential site areas (Figure VI-3). Most of these are at or near cinder cones. At the northeast end of the Kuukii Cinder Pit a <u>heiau</u> (Kukii Heiau) and spring have been recorded. Kaholuao-kahawai to the west is a possible <u>holua</u> slide with mythological connections to the goddess Pele. In the south central portion is a <u>holua</u> slide and an agricultural complex recorded by Hudson (1932). These sites lie to the west of the 1955 lava flow. Further to the west a lava tube was recorded by Bonk (1980a,b) and the Rycroft Coffee Plantation appears on Loebenstein's 1895 map. The two caves reported by Loebenstein in the east part of the Kapoho Subzone were almost certainly inundated by the 1960 lava flow (Figure VI-6). The entire eastern section of the subzone, except for the higher cinder cones and small <u>kipukas</u>, has been inundated by the 1960 lava flow. Because Kukii Heiau is on higher ground it has survived this flow. The 1955 lava eruption has inundated large areas in the east central portion and lands between the 1955 and 1960 lavas are cane fields.

Archaeological Potential

The following general observations apply to the potential for impact of geothermal development on tangible archaeological resources:

- The major concentration of known archaeological site areas is in the Kapoho Section of the Kilauea Lower East Rift Subzone, of which only one site area appears to be close to the conceptualized facility location - Holua slide and agricultural sites first recorded by Hudson in 1932 (Figure VI-3).

- Within the Kamaili Section of the Kilauea Lower East Rift and Kilauea Middle East Rift Subzones there are no known archaeological site areas near proposed geothermal facilities.

- All areas covered by lavas postdating 1800, particularly those areas covered by very recent flows have no archaeological potential (Figures VI-4, VI-5 and VI-6). There are, however, small kipuka areas within many of these flows which have the potential for containing archaeological sites.

- There have been major lava tube sites recorded in the Puna District in general (Emory, 1945, Olson, 1984). Lava tubes were preferred dwelling places and sources for fresh water in ancient Hawai'i. These features are difficult to identify in ground survey and there could be many undiscovered tubes on the older flow surfaces, including cane lands within all three subzones.

- Review of historical and archaeological records shows that early travellers and archaeologists have visited areas within all three subzones. However, systematic transect survey has been very limited and mostly confined to the southwest portion of the Kapoho Subzone (Bonk, 1980b; Bonk and Stemmermann, 1984; Rogers-Jourdane and Nakamura, 1984). Many sites within older flow surfaces may be as yet undiscovered. As a general archaeological rule the older the flow surface, the more likely sites are to be present. Similarly the older the flow surface, the heavier the vegetation and the greater the difficulty in finding archaeological sites either from the air or the ground.

Given the immense land areas (over 21,000 acres) and lack of access within the three subzones and even within the conceptualized geothermal development areas themselves a systematic archaeological survey of older flow surfaces is clearly out of the question. Mitigation of impact on potential site areas should be concerned only with specific potentially sensitive areas to be affected by well sites, power lines and roads on a project by project basis. The following approach is recommended.

- No further archaeological work should be required for facilities or portions of facilities located on recent lava flows.
- The boundaries and routes of wells, power lines and roads to be located in areas of older flows, particularly near known archaeological site areas, should be land surveyed and staked in the field and archaeologists should perform reconnaissance surveys of these specific areas before construction. In some heavily vegetated areas bulldozer grubbing should be permitted in conjunction with the archaeological reconnaissance in direct coordination with the field archaeologist.
- In unvegetated areas of the proposed facilities helicopter reconnaissance of surveyed and staked localities would be a complement to on-the-ground reconnaissance.
- If archaeological sites are found within the proposed power lines, roads or well sites during reconnaissance surveys, the facility location should be readjusted to avoid these sites. Given the large land areas and some locational flexibility of a project of this kind direct impact on archaeological resources could be avoided.

PART VII: LAND USE AND VISUAL IMPACT ANALYSIS

A. EXISTING CONDITIONS

1.0 Land Use and Zoning

The Puna District is located on the island of Hawaii's east coast; it is adjacent to the South Hilo District which contains the government, business and commercial center of Hilo. The district has a land area of approximately 500 square miles. Often characterized as rural/agricultural, the Puna area is, in fact, comprised primarily of vast expanses of open space. Large open recreation areas such as Hawaii Volcanoes National Park, unvegetated recent lava flows and a widely dispersed population contribute to the impression that much of the district is barren and undeveloped.

Puna today is a mixture of bedroom communities for people who work in Hilo, or are involved in small-scale specialized agriculture or subsistence activities. Owners of large tracts of land in Puna include: AMFAC; Bishop Estate; Lyman Estate; Hawaiian Paradise Park Corp.; W.H. Shipman, Ltd., and Campbell Estate.

The 1983 Hawaii County land use inventory categorizes approximately 237,500 acres of Puna's land (74 percent) as unused open space; 150,730 of these acres (over 60 percent) are in the State Agricultural District. At the time of the inventory, only 29,000 of the 191,790 acres county-zoned for agricultural use were actually being used for agricultural activities. The number of acres in agricultural use is currently less than the 1983 figure because of the closing of Puna Sugar in 1984.

In 1985, there were approximately 51,000 vacant parcels in Puna, ranging in size from 4,000 square feet to over 10 acres. Approximately 90% of these vacant parcels are zoned for agriculture.

A large number of large-lot subdivisions were created during the 1950s to the late 1960s, prior to the adoption of the County's present Subdivision Control Ordinance which requires a developer to complete specific site improvements when land is subdivided. Many of these "agricultural" subdivisions were actually constructed on recent lava flows. Most lack County-standard roads, water, and sewer lines; some portions are not served by electricity or telephone lines. In recent years, the relatively cheap land has resulted in rapid but widely-scattered single-family home development, with consequent increased taxpayer demand for government services.

No data for the subdivisions adjacent to the geothermal project sites are available. A door-to-door survey in 1984 found 152 households in the Leilani Estates subdivision, with a population approaching 400 (Anderson and Oyama, 1987). The only available indication of (actual or potential) population in the nearby subdivisions is the number of lots into which they are divided (on tax maps):

Hawaiian Holiday Estates	88 lots
Lanipuna Gardens	110 lots
Leilani Estates	2,266 lots
Nanawale Estates	4,289 lots.

In Leilani Estates, then, there were about 15 lots for every house standing at the time of the survey. This underscores the point that much land remains undeveloped and unoccupied in the subdivisions.

Many of the subdivided agricultural lots are owned by persons living outside of the state. In recent years some out-of-state owners have built homes on their lots and now live on them. If past trends continue, it can also be expected that a large proportion of the currently vacant parcels will also be developed with residences rather than being used primarily for agriculture.

Most existing industrial land uses in Puna are related to agriculture, for example macadamia nut and papaya processing. W. H. Shipman, Ltd.'s industrial park in Keeau is intended for light industrial uses, warehouses and high technology research facilities.

According to the County of Hawaii land use inventory (1983), there are approximately 148 acres of commercial land uses (including land for services) in Puna. A neighborhood shopping center was recently completed in Keeau.

Because Puna is relatively undeveloped, residents enjoy a variety of activities that can also produce supplemental income. These include hunting, fishing, limu and opihi gathering, and foraging for plants. It is common for people of the area to grow produce and fruit for their own consumption; excess production is sold to the public.

The Puna District is particularly well endowed with natural recreational areas. There are three beach parks and three parks that are rural or mountain types. Added to this are several State parks (including Lava Tree State Park within the

Kapoho GRS) and thousands of acres of federal forest reserve.

2.0 Land Use Within the Geothermal Resource Subzones

As of 1983, geothermal developers had acquired (by lease and/or purchase) a total of 41,400 acres in and adjacent to the three GRS in the Kilauea East Rift Zone. Although it is expected that only a small portion of this land area would be required for plants, well pads, pipelines and service roads, because the actual extent and location of the resource is still unknown, large areas of land are required for exploration and buffer zones.

Kapoho Section of the Lower East Rift Zone. According to the 1987 Hawaii County land use inventory, as derived from data for TMK Zone 1, Section 4, the area is zoned Open and Agriculture (A1a to A10a). Approximately 85 percent of land is presently unused open space. Residential use on agriculture-zoned land accounts for less than one percent of the total area.

Kamaili Section of the Lower East Rift Zone. The 1987 County of Hawaii land use inventory (derived from TMK Zone 1, Section 3) indicates that the zoning in this GRS is agriculture; approximately two-thirds of the area is A20a and one-third is A5a. Most of the subzone is presently unused open space.

Kilauea Middle East Rift Zone. The great majority of the land within the GRS is classified Forest Reserve on the County of Hawaii Puna District Zone Map. The extreme eastern portion of the GRS is zoned agriculture (A20a). True/Mid-Pacific Geothermal Venture has planned a road network within the GRS for geothermal exploration.

3.0 Infrastructure and Utilities

State Highway 11, Volcano Road, is the primary Hilo-Puna-Ka'u route. This highway serves the upper Puna region. The primary routes connecting lower Puna to Keeau and Hilo are the Pahoa Road (Hawaii 130), which runs from Keeau through Pahoa to Kalapana-Kaimu; the Kapoho Road (Hawaii 132), from Pahoa to Kapoho; the Puna Coast Road (Hawaii 137), which links Kapoho to Kalapana-Kaimu; and a portion of the Chain of Craters Road which is covered by lava for approximately 2 1/2 miles near Highway 130. The Hawaii Belt Road, Chain of Craters Road, the Kalapana-Kaimu bypass road and the majority of the Keeau to Pahoa road are all weather surfaced; those not subject to inundation by lava are in excellent to good condition. The others are in need of repair, widening or other improvements (U. S. MMS and DPED, 1987).

Other public streets and roadways within the district are under County jurisdiction and are periodically maintained and improved by them. Pohoiki Road, which serves the geothermal development area in the Kapoho Section of the Lower East Rift Zone, branches off from Highway 132 near Lava Tree State Park and continues to the lighthouse at Cape Kumukahi. This road is paved, narrow in places and in poor condition (Albert Matos, personal communication).

Puna's industrial infrastructure was put in place to serve agriculture; arterial roads and highways are adequate to handle the truck traffic associated with various agricultural endeavors. "Haul cane" roads provide access to former sugar lands; this type of road is privately owned and the responsibility of the landowner and/or the lessee.

Water, electricity and telephone services are basically confined to the older developed areas of Keeau, Pahoa and Kapoho and along the Volcano Highway from Keeau to Mountain View. Water and telephone service also extends to the Kalapana area but not all of that area is served.

Telephone service is provided by Hawaii Telephone Company which offers service throughout the district.

Electrical power is provided by HELCO and serves the most populated areas of the district. Power transmission is by overhead lines; the poles are typically shared by the telephone system. Base load power to serve the Puna District is currently generated at the main HELCO generating plant in Hilo. HELCO is proposing to construct two 69-KV overhead transmission lines and a new substation near Puna Geothermal Venture's proposed geothermal power plant. One 69-KV line will connect the new substation with an existing substation in Pahoa; the other will connect it with an existing substation at Kaumana, near Hilo. The construction contract for these lines would be between HELCO and the owners of Puna Geothermal Venture.

Gas systems are nonexistent in Puna. Gas is provided to individual homes by means of tanked liquefied propane at the request of the homeowner.

The public water supply and distribution system is operated and maintained by the County Department of Water Supply. There are five major public systems in the Puna District; these are located at Olaa-Mountain View, Pahoa, Kapoho, Kalapana and Keeau (substation of Olaa-Mountain View). Residents of the area without centralized water systems (including many in the Kapoho area), rely on the roof catchment method for their water supply. During periods of drought, the county assists families who rely on rain catchment in replenishing their water supply.

The Keeau station is planned to be extended toward Pahoa Drive; this expansion is anticipated to take place soon. A portion of the Pahoa system has been extended from Kaniahiku Village to Lava Tree State Park and to the HGP-A geothermal well site. Depending on funding there may be an expansion toward Hilo of this system. The goal is to connect with the Keeau system after it is expanded. Eventually the Kapoho system will be supplemented by tapping into the Pahoa system. Because of source problems, no definite date is set for expansion. There are no changes planned at the Kalapana and Olaa Mountain View systems (Craig Shimabukuro, personal communication).

There is no municipal sewer system in Puna. Sewage disposal in the district is by means of individual cesspools, septic tanks, or aerobic treatment units.

4.0 Public Facilities and Services

The County has implemented a solid waste management program for Puna. Open dumps have been closed and solid waste is now deposited at transfer stations, (large containers into which rubbish is disposed) and then transported for final disposal in landfill sites at either Hilo or Kona. Transfer stations are located at Kalapana, Pahoa, Keeau, and the Volcano Area. There is no municipal solid waste collection in Puna; the service is either provided by private contractors or individuals take their "rubbish" to the transfer station or landfill themselves.

There is no facility available exclusively for industrial waste. Clearance must be obtained from the State Department of Health (Environmental Services) before this type of waste can be disposed of in the existing landfills.

Pahoa has one full-time doctor. There is also a private clinic run by the Hilo Medical Group in Pahoa. Several doctors take turns servicing the Pahoa clinic. In addition, an examination room has been set aside in the Pahoa Neighborhood Center for use by the Health Department. There are no hospitals in Puna.

There are three schools in the Puna District: Keeau Elementary and Intermediate School; Mountain View School; and Pahoa High and Elementary. These schools have experienced significant growth in the past ten years.

Public schools in the Puna district are operating at capacity level. A new elementary school (K-6) is planned for the Pahoa/Keeau area. This is to relieve pressure on the existing K-12 school in Pahoa. The school is planned to open in 1991. A new elementary school is also planned for Keeau within the next ten years. The time table for this new school depends on approval of funds from the Legislature. By 1991, a new elementary school will be needed in this area. The present K-8 school will become an intermediate school once the elementary school is opened (Edward Matsushige, personal communication).

Two fire stations are located in the District at Pahoa and Keeau; both facilities are 24-hour a day operations. In addition, trucks manned by volunteers are stationed in Paradise Park and Hawaiian Beaches subdivisions. A volunteer program in the Volcano community is also planned (Ralph Yoshizumi, personal communication). One police station, located in Keeau, serves the entire Puna District.

5.0 Aesthetics

The following description of the Puna visual setting is taken from the Environmental Impact Statement for the Puna Geothermal Venture Project (Fluor Technology, Inc., 1987).

The Puna District is primarily comprised of volcanic uplands, puus, and craters; several lava flows have occurred in the district. The East Rift Zone is manifested at the surface as a linear belt, one to two miles wide, consisting of vents, faults and other volcano-tectonic related events.

The sea can be seen from several vantage points within the region because the land slopes gently to the ocean in three directions. The summit of Kilauea Volcano is another dramatic view that can be seen from the Puna District. Views in the region are limited because of the rainy weather and the amount of tree cover, especially for travelers along the region's main highways (Highway 130, Highway 132, and Highway 137).

The basic vegetation in Puna includes grassland/scrub, dry forest, woodland forest, mixed lowland forest and agriculture plantings. The bushes and grasses are low where the roads pass through scrub vegetation and the views are usually wide-angle or panoramic. In areas with forest cover, the view is generally restricted to the road corridor. Large canopy trees overarch the road to create tunnels in some areas; other tree-lined roads have species with a more vertical form which leave the sky above the road clearly visible.

Large fields northeast and southwest of Pahoa were formerly used primarily for sugarcane. These fields began reverting to scrub after the Puna Sugar Company ceased operation in the area. The most significant agricultural crop cover in Puna is currently papaya. Other crops include macadamia nuts, bananas and anthuriums. Pahoa and the surrounding area are rural and contain older structures, buildings, and landscaping.

B. POTENTIAL IMPACTS OF THE DEVELOPMENT ON LAND USE, INFRASTRUCTURE AND PUBLIC SERVICES

As presented in Part III, Economic Analysis, construction of the 500 MW system would span a 14-year period. In addition, periodic drilling and testing of replacement wells, estimated to be six annually, would be required throughout the economic life of the system. Total construction employment is expected to average about 240 jobs annually over the construction period.

The land area requirements for the plants, well pads, pipelines and service roads in the conceptual geothermal system depicted on Figure I-5 are presented in Table 7.1. Although in the conceptual 500 MW system less than 500 acres would actually be developed, because the extent and location of the resource is still unknown, large areas of land have been set aside for exploration and buffer zones.

Employment during operations is projected to total 200 jobs. This translates to a population increment of 480 people and 180 homes as a direct result of the geothermal development (See Part III, Economic Analysis).

1.0 Impacts on Land Use

Residential and Commercial Uses

Construction Phase. Traffic, noise, and dust from trucks going to and from the various construction areas within the three GRS and construction and installation of transmission lines within and between the GRS could affect commercial and residential land uses near roads, highways, and power line corridors throughout the Puna District. On the other hand, the impact of other drilling and/or plant construction activities on these land uses would be dependent on where the construction is taking place in relation to the commercial and residential areas near each GRS. For example, commercial and residential land uses would be more likely to be affected by dust and noise from construction equipment and drilling activities conducted within the Kapoho GRS than from similar activities conducted within the Kamaili and Kilauea Middle East GRS because the latter two GRS are further away from populated areas.

Operations. Although some residential development has taken place adjacent to the geothermal area, the location of the land, in and adjacent to the rift zone, makes it unsuitable and hazardous for most residential and commercial uses. There are numerous vacant parcels outside of the GRS areas which could be designated for residential and commercial use by the County of Hawaii if

Table 7.1 ESTIMATED LAND AREA REQUIRED FOR DEVELOPMENT

LAND USE	LENGTH	WIDTH	AREA	GRS AREA
KILAUEA MIDDLE EAST RIFT GRS				
Power Plant Sites (4)			5-8 Ac Ea	20-32 Ac
Well Pads (15)			2-3 Ac Ea	38-57 Ac
Primary Service Roads	5.8 mi.	30 ft		21 Ac
Well Field Service Roads	5.3 mi.	20 ft		13 Ac
Geothermal Fluid Lines	5.7 mi.	10 ft		7 Ac
Power Transmission Lines	5.8 mi.	48 ft		34 Ac
Miscellaneous Use				10 Ac
		Total GRS Area =		143-174 Ac
KAMAILI SECTION OF THE KILAUEA LOWER EAST RIFT GRS				
Power Plant Sites (4)			5-8 Ac Ea	20-32 Ac
Well Pads (15)			2-3 Ac Ea	30-45 Ac
Primary Service Roads	3.7 mi.	30 ft		13 Ac
Well Field Service Roads	4.6 mi.	20 ft		11 Ac
Geothermal Fluid Lines	4.6 mi.	10 ft		6 Ac
Power Transmission Lines	5.0 mi.	48 ft		29 Ac
Power Converter Station (1)			2 Ac	2 Ac
Miscellaneous Use				10 Ac
		Total GRS Area =		121-148 Ac
KAPOHO SECTION OF THE KILAUEA LOWER EAST RIFT GRS				
Power Plant Sites (4)			5-8 Ac Ea	20-32 Ac
Well Pads (12)			2-3 Ac Ea	24-36 Ac
Primary Service Roads	2.6 mi.	30 ft		9 Ac
Well Field Service Roads	2.6 mi.	20 ft		6 Ac
Geothermal Fluid Lines	3.1 mi.	10 ft		4 Ac
Power Transmission Lines	9.3 mi.	48 ft		54 Ac
Miscellaneous Use				10 Ac
		Total GRS Area =		137-161 Ac
		TOTAL SURFACE AREA =		401-483 Ac

required, therefore, the proposed geothermal development would have minimal impact on the supply of land for these uses in Puna.

Operating factors of geothermal wells and plants which could adversely affect surrounding property values and sales include: hydrogen sulfide emissions (which have the noxious smell of rotten eggs, even though the emissions pose no health hazard at low concentrations); noise from drilling, well venting, and plant operations; visual impact of the plant and well field; and, visual impact of steam emissions. According to Decision Analysts Hawaii, Inc. (Appendix D), the overwhelming factor affecting property values and sales near the HGP-A facility is the frequent emission and high level of hydrogen sulfide. The occasional noise from well venting is much less of a problem, and residents have adjusted to it. Noise emitted from the wells and visual impacts of the geothermal operations are also regarded as having an insignificant affect on property values and sales.

For the proposed geothermal power plants, the appropriate mitigating measure - one which is in fact planned - is to install control devices which would reduce hydrogen sulfide emissions to negligible levels - the smaller the emissions, the smaller the affected area.

Assuming (1) a half-mile impact radius for the HGP-A plant; (2) a worst-case situation for the proposed geothermal wells and power plants of emissions equal to 10 percent of the emissions from the original HGP-A operation (prior to installation of an efficient H_2S abatement system); and (3) emission concentrations which decline in proportion to the square of the distance from each emission source; then, the area in which property values would be adversely affected would lie less than 900 feet from each emission source. (See Appendix D for a complete assessment of the probable impact which the proposed 500 MW geothermal development would have on surrounding property values and sales.)

The proposed 500 MW geothermal development would generate the need for additional residentially-zoned land to accommodate the housing requirements expected to be induced by population supported by the project. There is a sufficient supply of vacant and/or appropriately zoned land available in Puna and the adjacent South Hilo District at the present time, therefore, impacts of the proposed geothermal development should be minimal.
New residences would generate the need for additional commercial, light industrial and recreational land uses. These uses could be located in either Puna or Hilo. The

impact of the development on available land would be expected to be insignificant.

The development should have minimal impact on resort land uses. There are no major hotels in the District; visitor accommodations are essentially limited to Bed-and-Breakfast Inns. Future growth of the visitor industry on the island of Hawaii is expected to be concentrated in the South Kohala/North Kona area, on the west coast of the island.

<u>Industrial Uses</u>

Construction Phase. There would be minimal impact on agricultural processing activities in the Puna area during the construction period. The impact on light industrial land uses in the area should be positive as space may be required for baseyards, machine shops, and other activities that would facilitate the construction process.

Operations. The influence of the 500 MW development could extend outside of the GRS. Support industries could be attracted to the area; this could generate a need for additional industrial-zoned land in Puna and/or South Hilo.

<u>Agriculture</u>

Although a large proportion of the land within the GRS is zoned for agricultural use, it is primarily unused. The impact of removing this land from agriculture is not expected to be significant, due to the fact that sugar production in the area is no longer viable and there appears to be an adequate supply of land available for diversified agriculture activities. Most agricultural land uses would be compatible with geothermal development, even if such uses are located adjacent to the plants.

<u>Open Space</u>

Development on land currently unimproved with structures could be perceived to be a loss of open space. Because Puna is largely undeveloped, people enjoy a variety of outdoor activities within the District i.e., hunting and foraging for plants. Withdrawal of land for the geothermal development could have some impact on these activities.

Access to gathering and hunting areas may be temporarily restricted from time-to-time because of construction activities. Public access to shoreline recreation areas would not be a problem because the GRS are all located mauka of the coastal highways.

At full operation, most of the area covered by plants and associated well pads and buffer zones would be fenced for security reasons. It should be emphasized, however, that the lands involved are private property and access to them could legally be restricted even if the geothermal development did not occur.

2.0 Impacts on Infrastructure and Utilities

Highways, Roads and Traffic

Construction Phase. An increase in the number of heavy vehicles using highways and roads in the region is anticipated during the construction phase of the project. Even though heavy equipment would be moved to the sites and most likely left there during the construction period, it is expected that the daily number of trucks using area roads would be greater than before the project. This increase in traffic could possibly cause traffic tie-ups resulting in temporary annoyances for area residents. Restricting truck traffic to off-peak daytime hours would help to mitigate this impact.

Additional traffic will be generated by employees involved in the construction of the plants and associated infrastructure. Although it is impossible at the present time to determine where these workers would reside on the island of Hawaii, traffic generated by construction worker vehicles trips to/from work would not expected to adversely affect traffic flow on the Hawaii highway network. Assuming construction workers have been recruited from the local labor pool, they would probably be making work-trips to other construction sites if the project was not constructed. In-migrants would probably reside in areas near to the construction site. Care should be taken, however, to insure that intersections near construction areas have sufficient capacity to accommodate the increased number of vehicles generated by construction activities in the area or localized traffic tie-ups could occur.

Operations Phase Based on an estimate of 10 to 18 vehicle trips per day during operations of the 25 MW Puna Geothermal Venture Project (Fluor Technology, Inc., 1987), approximately 200 to 360 vehicle trips per day would be generated by the proposed 500 MW geothermal development. It is beyond the scope of this environmental review to assign these trips to the Puna highway network, however, considering that plants in the development scenario are sited a minimum one kilometer apart, impact on any one segment of the highway system would be expected to be minimal.

Power

During construction, electrical power would be provided by HELCO. During operation, on-site power requirements would normally be met using power generated by each plant itself. Diesel generator units would usually be provided as emergency backups if system power fails.

The population generated by the development would have no adverse impact on the ability of HELCO to continue to provide electrical services to residents. Electricity is currently being provided from the main HELCO generating plant in Hilo.

Water Supply and Distribution

Construction Phase. When mud drilling of geothermal wells is required, approximately 2,000 barrels of water per day for drilling in the softest formations and approximately 100 barrels per day would be required when drilling in hard formations. Where municipal water is not available, dedicated wells and/or rain catchment systems could be used to meet on-site water requirements.

Operations. Service water is required for drinking water, sanitation, occupational safety and chemical mixing. Normal usage during operation is estimated at 200 gpd for a 25 MW plant (Fluor Technology, Inc., 1987). At this rate, approximately 4,000 gpd would be required for the 500 MW development. Depending on the location of a particular plant, service water would be provided by the County water main, developer constructed wells or rain catchment systems.

Makeup water is the replacement water which would be needed to offset the evaporation and other losses from the cooling system. The primary source of makeup water would be the steam condensate. If needed, rain catchment water or trucked in water could be used for that purpose (Fluor Technology, Inc., 1987).

The average water consumption for each additional home generated by the proposal is estimated to be 426 gpd, for a total potential increase of 0.77 mgd for a total of 180 homes directly supported by the project.
The 500 MW development and associated potential population increase could have a high impact on existing water sources and water delivery systems in the area. Additional resources may have to be developed and the

water distribution system may have to be improved. It is possible that increased economic activity and population in the area (and thus an increased tax base) would make it feasible for the County of Hawaii to improve the existing water distribution system.

Sewerage

There is no municipal sewer system in the Puna area. Because the proposed plants are widely dispersed, domestic wastewater would probably be disposed of on-site in cesspools if approved by the State Department of Health. It is not expected that this method of wastewater disposal would impact public drinking water sources. No hazardous chemicals or other potentially toxic liquid wastes would be disposed of in the cesspools.

Because cesspools and septic tanks are the primary methods of wastewater disposal for unsewered areas of the Puna District, the use of these systems would probably continue until increased population distribution and density beyond that attributable to the proposed project make it economically feasible to install a municipal system. The expected impact of the project would be very low.

3.0 Impacts on Public Facilities and Services

Construction Phase

Impacts of construction activities on public facilities and services is expected to be insignificant, although in-migrant construction workers and their families could impact recreation, medical, and protective services facilities.

Operations Phase

Solid Waste. The only solid waste that would be produced at a generating facility would be sludge accumulating in cooling tower basins. The sludge could consist of sulfite, iron, and bacterial growth. It is expected to be a nonhazardous waste and would be removed periodically from the cooling tower basins and placed in a wellpad sump for evaporation. The solids that remain would be periodically covered with soil on-site. If the sludge proved to be toxic, it would be transported and disposed of according to applicable hazardous waste regulations (Fluor Technology, Inc., 1987). There would be no direct impact on solid waste disposal facilities and services in the Puna District. Domestic refuse generated by the plants would be expected to have a very low impact on solid waste disposal facilities.

Since there is no municipal home refuse collection provided by the County of Hawaii, residents will continue to haul their own refuse to private or county disposal areas, or provide for disposal by private contractors. The Hilo sanitary landfill is planned to be expanded by 60 acres, therefore, the impact on municipal solid waste facilities would be low to moderate.

Other Facilities and Services It is not anticipated that operation of the proposed 500 MW geothermal system would adversely impact other facilities and services. It is expected that each plant would provide for its own security and that local police would only be called in when necessary; on-site fire-fighting capability would also be provided. Medical facilities in the area would be adequate to handle a major emergency, however, on-site medical care should be provided for minor industrial accidents and for first-aid for major accidents until an ambulance and/or med-evac helicopter arrives.

Assuming 2.2 firemen per 1,000 resident population as the required standard, the need for one new fireman would be generated by the direct population increase. This position would likely be located within an existing fire station that serves the district. Assuming 2.0 police officers per 1,000 resident population as the required standard, the need for one new police officer would be generated by the population increase. This individual would either join the existing Hilo police force or the smaller force located in Keaau which services the entire Puna District. The existing facilities would be capable of continuing to meet the community's needs for medical services.

The additional project-related population will generate higher usage rates of recreation facilities, however, the impact would be very low.

Approximately 100 school-age children could be included in the expected increase in population. Enrollment in all schools in the area, particularly at the Pahoa School, increased dramatically during the 1970s. The Department of Education has proposed the design and construction of new facilities at Keaau and Pahoa; these improvements should satisfy future requirements for additional educational facilities in the district.

C. VISUAL IMPACT ANALYSIS

The visual analysis is based on the conceptual geothermal system layout presented in Figure I-5. It should be noted that other configurations would probably generate different visual impacts.

1.0 Methodology

In general, the physical characteristics of each subzone were identified and evaluated, then these characteristics were related to the characteristics of the proposed power plants and associated facilities. The effects and level of impact were then determined based on the above factors.

Existing Conditions

Vegetation. The existing vegetation types within the subzones were determined from Char and Lamoureux (1985a). They were studied and ranked on a classification system of high visual impact (1) to low visual impact (6). The classifications and their descriptions are:

1) Lava: flows with pioneer vegetation.
2) Grassland/scrub: vegetation including dry scrub, dry grass and scrub ranging in height from 1 to 4 meters.
3) Ag Land: agricultural land including sugar cane and papaya.
4) Dry Forest: dry forest vegetation with open to closed canopies ranging in height from 5 - 10 meters.
5) Woodland/Forest: vegetation that includes a wide variety of exotic shrubs, tree ferns, and subcanopy trees reaching a height of up to 20 meters.
6) Mixed Lowland Forest: includes a dense mixture of native trees and introduced vegetation. The height varies from low stature to medium to tall older forests.

Figure VII-1 is a graphic interpretation of the vegetation classification description in relation to a proposed facility (transmission line). The graphic is representative of all three GRS.

Other Conditions. Slopes, topography and significant features, such as puus, within each subzone were identified and evaluated. Viewplanes across each area were determined.

After existing conditions were analyzed, it was determined that there was no cumulative visual effect of the proposed development if the power plants were spaced a minimum of one kilometer apart. Each subzone, therefore, was evaluated

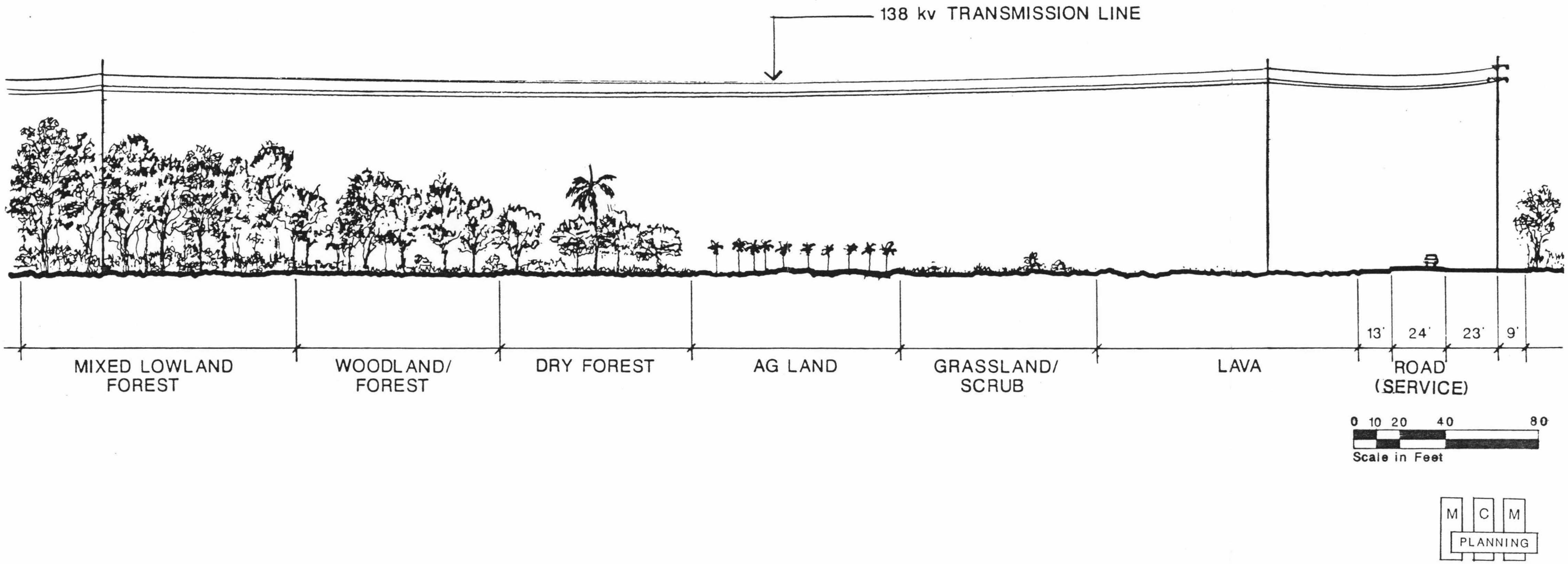


Figure VII-1
TRANSMISSION LINE ELEVATION

separately to determine the visual impact of plant complexes within its boundaries from surrounding roadways.

Development Characteristics

The visual character of the facilities, such as height and bulk, was determined and assessed for factors such as visibility of plants, well pads and transmission lines from major roads. The probable visual effects of the development were then intuitively evaluated for each subzone, taking into consideration the existing vegetation of each development area.

From the above analysis, the worst case scenarios for each subzone, e.g. areas of highest probable visibility from the roadways within each subzone, were identified. Sections showing vegetation and topography were developed for each subzone to determine sight lines from major roadways towards the power plant. Figure VII-2 is a key map locating each section. The sections also illustrate proposed mitigation measures, i.e. vegetation screens for power plants etc. Figure VII-3, Power Plant Elevation, generically illustrates these mitigating measures.

2.0 Visual impact analysis

Kilauea Middle East Rift GRS (Figure VII-4)

The visual impact of geothermal development within this GRS from Highway 130 at Queens bath (5.3 miles to the subzone boundary) is insignificant because of distance and topography and the view is blocked by dense vegetation. The visual impact from the closest national park boundary to the subzone boundary (3.6 miles) is also insignificant because of the distance and dense vegetation. Development in the subzone would have very low visual impact; the entire GRS is not visible from the road because of topography and dense vegetation.

Kamaili Section-Kilauea Lower East Rift GRS (Figure VII-5)

The development within this GRS, as depicted in Figure I-5, would be mauka of Highway 130. There would be no obstruction of views to the ocean. Section AA shows a view through lava, however, visual impact could be low if the facilities were sited so that they were hidden by Iilewa crater. In addition, dense vegetation blocks the sight line from the highway (130) to the power plant.

Section BB goes from Highway 130 through two proposed power plants and the possible location of the AC/DC

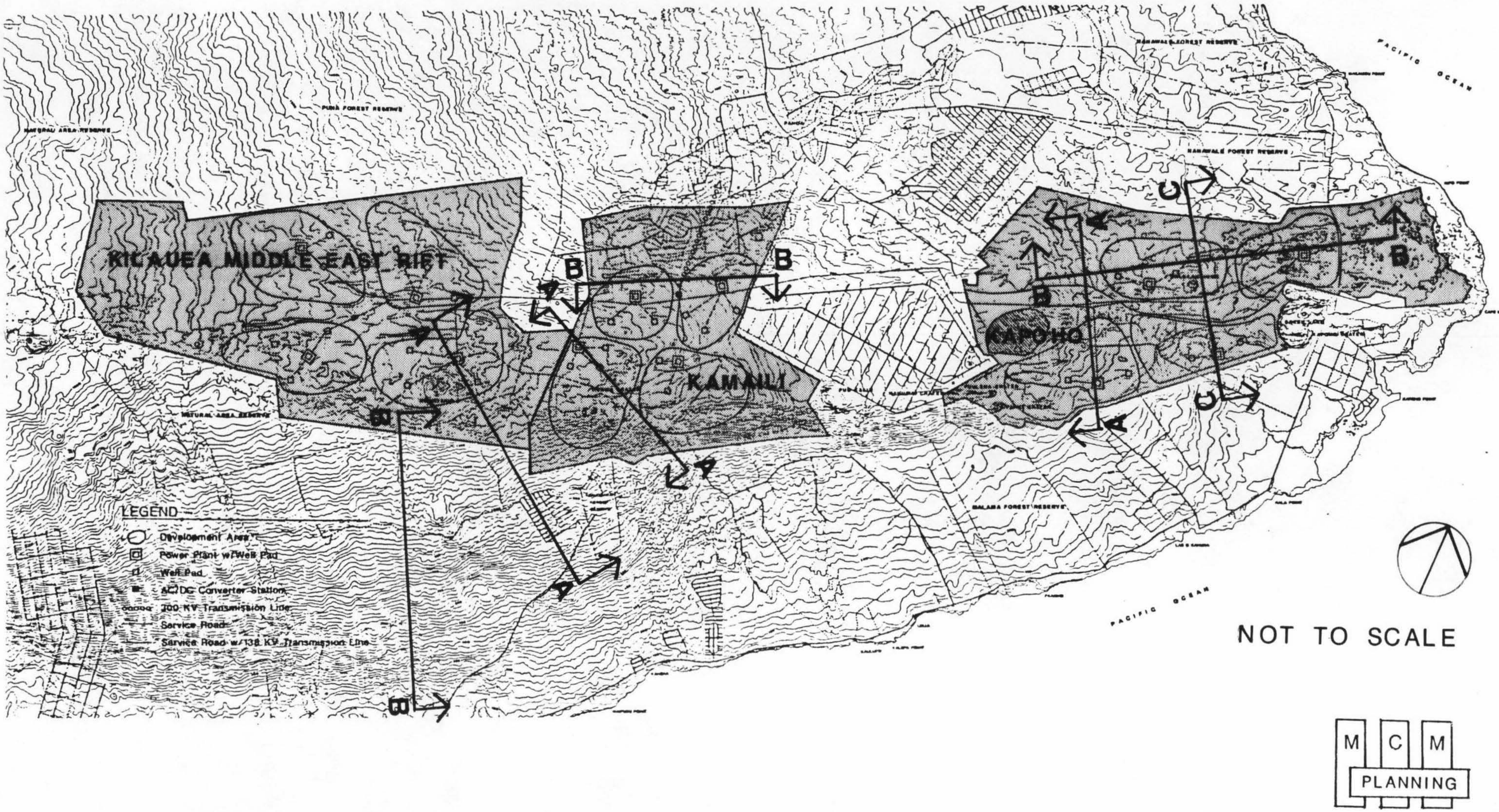


Figure VII-2

VISUAL IMPACT KEY MAP

converter station. Visual impact in this section would be low because it is all in dense woodland forest vegetation. The 138-KV transmission line would be visible if it crosses Highway 130, otherwise, the sight line is not affected by the power plants or converter station due to existing dense vegetation.

The Leilani Estates perimeter road is 1500 feet away from conceptual 138 KV inter-zonal transmission line, however, because of heavy vegetation it should be virtually invisible from residences in the subdivision.

<u>Kapoho Section-Kilauea Lower East Rift GRS</u> (Figure VII-6)

Section AA from Highway 132 towards a power plant shows low impact due to topography and existing vegetation. Even the transmission lines would be invisible from this sight line.

There are two sight lines illustrated in Section BB. There would be low visual impact from Highway 132 due to existing vegetation, therefore there would be no mitigation necessary. The power plant, as viewed from Highway 137, is highly visible due to the surrounding lava field terrain. A vegetation screen around the power plant perimeter is proposed to minimize the visual impact. When mitigated by this means, the visual impact of the plant from Highway 137 would be low.

Section CC illustrates an area of potentially high visual impact. Visual impact is high from Highway 132 because the transmission line crosses the highway in the area. From Highway 132, the elevation is higher than the power plant and the vegetation in the area is sparse, therefore, visual impact could be very high. A vegetation screen along the perimeter of the power plant is proposed to minimize visual impact, however, because of the terrain the plant would not be hidden from view and thus visual impact would still be moderate.

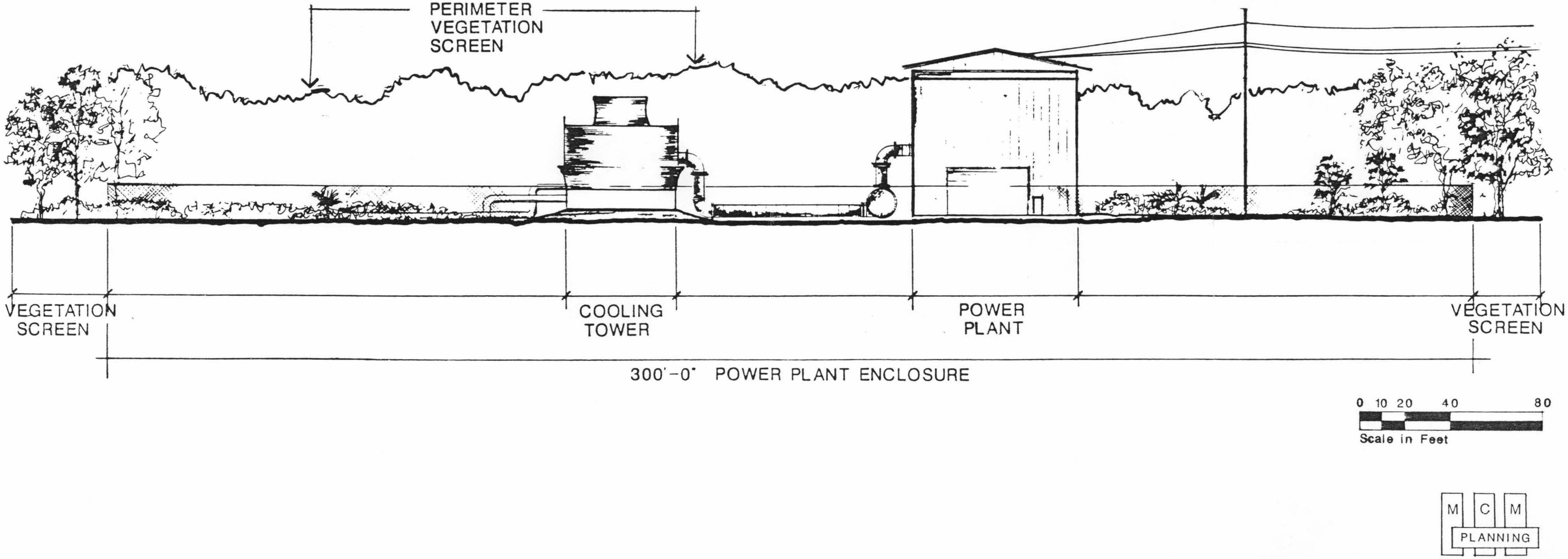


Figure VII-3
POWER PLANT ELEVATION

PART VIII: SOCIAL IMPACT ANALYSIS

A. EXISTING CONDITIONS

1.0 Regional Overview

The island of Hawaii is the largest of the Hawaiian chain, with an area exceeding 4,000 square miles, but it is the least densely populated county in the state, with fewer than 30 people per square mile. In mid-1986, the population reached an estimated 111,800 (DBED, 1987b), suggesting an annualized average 3.15 percent growth for the first part of the 1980s. The majority of the population lives on the eastern side of the island, although the West Hawaii population has been growing at a generally faster overall rate.

In addition to simple population growth, the island underwent various demographic changes from 1970 to 1980, as shown in Tables 8.1 to 8.4. Some of the more significant of these include: (a) the ethnic composition changed; e.g.. the proportion of residents of Japanese ancestry declined from 38 to 27 percent of the population (Table 8.1) while the number of Hawaiians and part-Hawaiians increased from 12 to 19 percent and the number of Caucasians increased from 29 percent to 35 percent of the population; (b) education levels increased (Table 8.1) as evidenced by the doubling of the percentage of adults with post-high-school education; and, (c) the civilian labor force increased by 58 percent, with the addition of 15,000 workers (Table 8.2). In addition, the industrial profile of workers shifted somewhat away from agriculture and manufacturing, toward retail and professional activities.

During the decade of the 1970s, the resident housing stock increased by 79 percent (Table 8.4). Occupied units increased by 69 percent, while the average household size dropped 14 percent. The proportion of occupied homes that were owner-occupied increased, while the proportion of substandard units declined markedly. However, rentals increased as a proportion of median family income.

Although agriculture overshadowed all other economic ventures on the island of Hawaii for much of this century, tourism has now become the largest single source of income for the county. Visitor expenditures amounted to $344 million in 1986. In that year, sugar production was valued at $74 million, and the total agricultural production of the county was valued at $166 million (DBED, 1987b).

Table 8.1:

Total Population and Demographic Breakdowns: County of Hawaii and Various Parts of Study Area, 1970 and 1980

	COUNTY OF HAWAII		LOWER PUNA (C.T. 211)		UPPER PUNA (C.T. 210)		PAHOA CDP		KEAAU CDP		VOLCANO (E.D.351)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL POPULATION	63,468	92,053	1,352	4,696	3,802	7,055	924	923	951	775	N/A	1,181
	%	%	%	%	%	%	%	%	%	%	%	%
ETHNICITY												
Caucasian	28.8	35.0	17.3	40.9	26.4	44.7	6.3	8.1	15.2	20.6	N/A	59.8
Japanese	37.5	26.6	37.9	14.9	41.7	22.0	N/A	43.0	N/A	35.4	N/A	16.8
Chinese	2.9	1.7	4.1	1.3	0.8	1.5	N/A	0.9	N/A	1.0	N/A	2.4
Filipino	16.5	13.9	22.3	16.6	22.4	16.8	N/A	25.5	N/A	33.7	N/A	2.7
Hawaiian	12.3	18.8	17.8	21.6	5.5	10.6	N/A	20.2	N/A	7.7	N/A	12.6
Other	2.0	4.1	0.5	4.7	3.2	4.3	0.0	2.4	0.5	1.6	N/A	5.6
AGE												
Less than 5 yr.	8.6	9.1	7.6	11.8	7.8	9.1	7.4	9.1	8.3	6.2	N/A	10.5
5 - 17 yr.	27.8	21.5	24.6	23.9	24.1	19.8	25.3	17.0	22.6	22.1	N/A	18.2
18 - 64 yr.	54.4	59.2	52.1	56.4	55.9	57.1	53.0	58.8	57.6	56.2	N/A	59.8
65 or more yr.	9.2	10.2	15.7	7.9	12.1	14.0	14.3	15.1	11.5	15.5	N/A	11.5
Median age	28.9 yr	29.4 yr	N/A	27.0 yr	N/A	30.2 yr	N/A	31.3 yr	N/A	35.6 yr	N/A	29.8 yr
PLACE OF BIRTH*												
Hawaii	NC	70.5	NC	61.3	NC	57.2	N/A	57.0	N/A	63.1	N/A	59.4
Other U.S.**	NC	20.0	NC	29.1	NC	27.2	N/A	21.1	N/A	4.4	N/A	36.1
Foreign country	NC	9.4	NC	9.6	NC	15.5	N/A	21.9	N/A	32.5	N/A	4.5
RESIDENCE 5 YRS. PREVIOUS (people aged 5+)												
Same house	62.5	52.9	74.1	40.7	62.9	46.3	N/A	48.8	N/A	64.6	N/A	46.4
Same island	NC	24.9	NC	19.6	NC	24.4	N/A	44.1	N/A	24.8	N/A	15.9
Different island	NC	8.1	NC	13.8	NC	8.4	N/A	3.3	N/A	3.0	N/A	26.0
Different state	NC	11.1	NC	16.7	NC	16.5	N/A	0.0	N/A	1.8	N/A	11.7
Different country	NC	3.1	NC	9.1	NC	4.4	N/A	3.8	N/A	5.8	N/A	0.0
EDUCATION* (people aged 25+)												
Less than H.S.	53.2	43.8	55.0	16.7	40.3	20.0	N/A	43.2	N/A	38.6	N/A	9.2
H.S. graduate	31.6	27.6	35.2	51.6	49.7	45.8	N/A	34.4	N/A	41.6	N/A	39.9
Some post H.S.	7.6	14.3	3.4	22.1	4.7	19.6	N/A	9.5	N/A	6.9	N/A	30.0
College, 4+ yr.	7.5	14.3	6.4	9.6	5.3	14.6	N/A	12.8	N/A	12.8	N/A	20.9

Notes: *Figures based on 15% sample; hence, numbers represent estimate.
**Including persons born in U.S. territories, and persons born abroad or at sea to American parent/s.
"CDP" = "Census Designated Place."
"NC" = 1970 categories or bases "Not Comparable" to 1980 (1970 Census kept a "non-response" category, while 1980 Census allocated non-responses to other categories shown).
"N/A" = "Not Available" in published form.

Sources: U.S. Bureau of the Census, 1970 Census of Population and Housing--Census Tracts--Honolulu, Hawaii, PHC(1)-88; 1980 Summary Tape Files 1-A and 3-A; State of Hawaii, 1973, Community Profiles for Hawaii. City and County of Honolulu, Department of Information Systems - Special Run; U.S. Bureau of Census, 1970.

Table 8.2:

Labor Force Size and Characteristics: County of Hawaii and Various Parts of Study Area, 1970 and 1980

	COUNTY OF HAWAII		LOWER PUNA (C.T. 211)		UPPER PUNA (C.T. 210)		PAHOA CDP		KEAAU CDP		VOLCANO (E.D.351)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
<u>POTENTIAL LABOR FORCE (aged 16+)</u>	43,075	67,205	804	3,163	2,877	5,204	N/A	701	N/A	646	N/A	859
not in labor force	39.5%	38.7%	47.9%	48.0%	41.5%	42.7%	N/A	58.9%	N/A	58.7%	N/A	43.1%
armed forces	0.4%	0.3%	0.0%	0.3%	0.0%	0.3%	N/A	0.0%	N/A	0.0%	N/A	1.9%
civil. labor force	60.1%	61.0%	52.1%	51.7%	58.5%	57.0%	N/A	41.2%	N/A	41.3%	N/A	55.1%
<u>CIVILIAN LABOR FORCE</u>	25,889	41,006	419	1,635	1,684	2,968	N/A	412	N/A	379	N/A	473
unemployed	2.7%	7.0%	2.9%	11.9%	4.6%	13.5%	N/A	3.6%	N/A	5.8%	N/A	19.0%
<u>TOTAL EMPLOYED CIVILIAN LABOR FORCE</u>	25,180	38,150	407	1,441	1,606	2,598	N/A	397	N/A	357	N/A	383
<u>OCCUPATION</u>												
service	16.3%	16.5%	0.9%	14.3%	10.3%	12.3%	N/A	8.3%	N/A	19.8%	N/A	13.6%
manager./profes.	NC	20.0%	NC	11.3%	NC	17.7%	N/A	7.8%	N/A	11.5%	N/A	18.0%
technical, sales & adminis.	NC	26.1%	NC	18.5%	NC	23.4%	N/A	19.6%	N/A	17.1%	N/A	19.8%
farm/fish/forest	NC	10.3%	NC	16.3%	NC	15.5%	N/A	36.3%	N/A	10.6%	N/A	19.6%
precision, craft, repair	NC	12.7%	NC	19.6%	NC	12.7%	N/A	10.3%	N/A	9.2%	N/A	20.4%
operators, fabricators, laborers	NC	14.4%	NC	19.9%	NC	18.4%	N/A	17.6%	N/A	31.7%	N/A	8.6%
<u>INDUSTRY (selected)</u>												
agric., forest, fish, mining	12.5%	11.2%	N/A	16.7%	N/A	16.1%	N/A	40.3%	N/A	10.4%	N/A	18.3%
construction	10.6%	9.1%	5.7%	12.3%	7.8%	10.9%	N/A	9.1%	N/A	3.4%	N/A	14.9%
manufacturing	15.0%	8.3%	8.1%	9.6%	25.6%	10.9%	N/A	3.3%	N/A	37.8%	N/A	2.1%
retail trade	14.8%	17.5%	4.9%	13.3%	15.7%	13.0%	N/A	4.8%	N/A	10.6%	N/A	11.5%
financial, insur., real estate	2.8%	5.7%	3.9%	3.5%	2.1%	5.8%	N/A	4.0%	N/A	2.2%	N/A	5.7%
personal, entertain. & recreat. services	11.2%	10.9%	N/A	6.2%	N/A	4.9%	N/A	6.3%	N/A	2.8%	N/A	8.6%
health, educ, & professional	14.1%	16.7%	10.3%	13.2%	9.3%	17.1%	N/A	12.1%	N/A	18.8%	N/A	8.4%
public adminis.	6.5%	7.3%	2.7%	8.2%	6.5%	8.3%	N/A	5.0%	N/A	2.8%	N/A	14.9%
<u>COMMUTE TO WORK</u>												
45 minutes or more	N/A	6.0%	N/A	9.4%	N/A	4.9%	N/A	2.3%	N/A	0.0%	N/A	18.8%
mean travel (min.)	N/A	16.5 m	N/A	26.1 m	N/A	20.6 m	N/A	20.9 m	N/A	11.6m	N/A	34.8 m

<u>Notes:</u> All figures based on 15% sample; hence, numbers represent estimates.
"<u>N</u>/<u>A</u>" = "<u>N</u>ot <u>A</u>vailable" in published form. "<u>NC</u>" = 1970 categories or bases "<u>N</u>ot <u>C</u>omparable" to 1980 Census.

<u>Sources:</u> U.S. Bureau of the Census, <u>1970 Census of Population and Housing--Census Tracts--Honolulu, Hawaii</u>, PHC(1)-88; 1980 Summary Tape File 3-A; State of Hawaii, 1973, <u>Community Profiles for Hawaii</u>.

Table 8.3:
Family Characteristics and Income Levels: County of Hawaii and Various Parts of Study Area, 1970 and 1980

	COUNTY OF HAWAII		LOWER PUNA (C.T. 211)		UPPER PUNA (C.T. 210)		PAHOA CDP		KEAAU CDP		VOLCANO (E.D.351)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
<u>POPULATION IN FAMILIES</u>	N/A	81,728	N/A	2,136	N/A	6,072	N/A	808	N/A	719	N/A	1,017
as percentage of total population	N/A	88.8%	N/A	90.8%	N/A	86.1%	N/A	87.5%	N/A	92.8%	N/A	86.1%
<u>NUMBER OF FAMILIES</u>	14,533	22,825	325	1,181	901	1,783	216	219	215	178	N/A	320
	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	%	%	%	%
<u>HEAD</u>												
Husband/wife	87.1	82.1	81.5	82.6	85.5	81.5	82.9	91.8	83.3	74.7	N/A	86.9
Male only	5.2	5.2	12.3	3.6	6.9	7.2	11.1	3.2	8.8	7.9	N/A	2.2
Female only	7.7	12.7	6.5	13.7	7.6	11.3	6.0	5.9	7.9	17.4	N/A	10.9
<u>WITH OWN CHILDREN UNDER 18</u>	57.4	52.7	44.6	59.6	48.1	49.9	N/A	47.0	N/A	37.6	N/A	47.5
Female head	7.7	7.4	62.5	9.4	2.9	7.4	N/A	2.3	N/A	2.8	N/A	10.9
<u>BELOW POVERTY LEVEL</u>	9.7	10.3	12.1	17.4	9.2	12.4	N/A	15.1	N/A	4.5	N/A	9.1
<u>MEDIAN FAMILY INCOME</u>	$9,750	$19,132	$7,603	$13,843	$8,371	$18,015	N/A	$14,132	N/A	$23,750	N/A	$20,750
<u>NON-FAMILY HOUSEHOLDS</u>	N/A	6,432	N/A	278	N/A	584	N/A	61	N/A	61	N/A	121
percentage below poverty level	N/A	27.8%	N/A	35.6%	N/A	33.9%	N/A	59.0%	N/A	32.8%	N/A	25.6%

<u>Notes:</u> All figures (except "Population in Families" and "Non-Family Households") based on 15% sample; hence, numbers represent estimates. "<u>N/A</u>" = "<u>N</u>ot <u>A</u>vailable."

<u>Sources:</u> U.S. Bureau of the Census, <u>1970 Census of Population and Housing--Census Tracts--Honolulu, Hawaii</u>, PHC(1)-88; 1980 Summary Tape File 3-A; State of Hawaii, 1973, <u>Community Profiles for Hawaii</u>.

Table 8.4:
Housing Stock and Characteristics: County of Hawaii and Various Parts of Study Area, 1970 and 1980

	COUNTY OF HAWAII		LOWER PUNA (C.T. 211)		UPPER PUNA (C.T. 210)		PAHOA CDP		KEAAU CDP		VOLCANO (E.D.351)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL YEAR-ROUND HOUSING UNITS	18,972	33,854	524	1,594	1,290	2,810	303	301	260	261	N/A	563
vacant (total)	9.0%	13.9%	17.9%	9.0%	15.3%	15.3%	6.3%	5.6%	2.7%	1.9%	N/A	22.0%
vacant for sale	N/A	1.3%	1.1%	1.1%	1.1%	1.3%	N/A	0.7%	N/A	0.4%	N/A	1.2%
vacant for rent	N/A	5.6%	1.0%	1.5%	0.5%	1.4%	N/A	2.6%	N/A	0.0%	N/A	1.4%
held for occas'l use	N/A	2.5%	N/A	2.3%	N/A	4.4%	N/A	0.3%	N/A	0.0%	N/A	9.4%
other	N/A	4.5%	15.8%	4.1%	13.7%	8.1%	N/A	2.0%	N/A	1.5%	N/A	9.9%
TOTAL YEAR-ROUND OCCUPIED UNITS	17,260	29,237	430	1,450	1,092	2,381	284	284	253	256	N/A	439
TENURE												
owner-occupied	56.9%	60.6%	71.6%	71.4%	77.1%	75.9%	68.0%	64.1%	74.3%	64.1%	N/A	68.3%
renter-occupied	43.1%	39.4%	28.4%	28.6%	22.9%	24.1%	32.0%	35.9%	25.7%	35.9%	N/A	31.7%
SELECTED CONDITIONS												
lacking some or all plumbing	17.2%	8.1%	56.0%	13.8%	22.3%	17.8%	40.9%	10.2%	17.7%	5.1%	N/A	11.4%
1.51 or more persons/room	6.5%	5.0%	7.9%	6.9%	4.8%	7.3%	7.7%	8.1%	4.3%	3.5%	N/A	4.3%
PERSONS PER HOUSEHOLD	3.61	3.09	3.12	3.24	3.44	2.96	3.21	3.25	3.60	3.03	N/A	2.69
MEDIAN CASH RENT (renter-occupied)	$54	$223	$30	$260	$53	$232	$ 0 to $40	$135	$ 0 to $40	$110	N/A	$257
as % of median family income	6.6%	14.0%	4.7%	22.5%	7.6%	15.5%	N/A	11.5%	N/A	5.6%	N/A	14.9%
MEDIAN VALUE* (owner-occupied)	$24,800	$70,300	$19,200	$47,000	$16,600	$54,700	$15,000 to $19,000	$59,700	$10,000 to $19,999	$54,200	N/A	$59,200
MEDIAN MONTHLY MORTGAGE* (owner-occupied)**	N/A	$371	N/A	$295	N/A	$360	N/A	$403	N/A	$197	N/A	$376
as % of median family income	N/A	23.3%	N/A	25.6%	N/A	23.9%	N/A	34.2%	N/A	10.0%	N/A	21.7%

Notes: * For 1980, median values are for non-condominium housing units.
** Figures based on 15% sample; hence, numbers represent estimates.
"N/A" = "Not Available."

Source: U.S. Bureau of the Census, 1970 Census of Population and Housing--Census Tracts--Honolulu, Hawaii, PHC(1)-88; 1980 Summary Tape Files 1-A and 3-A; State of Hawaii, 1973, Community Profiles for Hawaii.

The Big Island's agricultural situation is mixed. With the closing of Puna Sugar Company in 1984, Hawaii County's sugar production dropped by 18 percent. Diversified agricultural activities have been extensively explored. The 1986 production value for diversified agriculture in Hawaii County, $91.8 million, amounted to an increase of 35 percent over the 1984 value. Among the crops contributing to that value are macadamia nuts, coffee, papayas, and flowers. A food irradiation facility has been proposed to reduce past obstacles to successful exportation of papaya and other food products.

High technology investments also figure in the Big Island economy. These include astronomical observatories on the peaks of Mauna Kea and Mauna Loa, as well as ocean energy research and related aquaculture activities in Kona. The new Hawaii Ocean Science Technology (HOST) Park is intended to support aquaculture and related ventures, and various forms of space-related development -- including a possible commercial launch facility in Ka'u -- are under exploration by the State and County governments.

2.0 Puna Overview

The Puna District is located on the island of Hawaii's east coast; it is comprised of U.S. census tracts 211 (here referred to as "lower Puna") and 210 ("upper Puna") (Figure VIII-1). Upper Puna extends along Route 11 (or Mamalahoa Highway, the principal belt road circling the island), from the outskirts of Hilo, in a generally southwesterly direction through Keaau, Mountain View, and Glenwood, to Volcano. Lower Puna is linked at the north to upper Puna and to the rest of Hawaii County by Route 130, which runs southeast and south from Keaau to the lower Puna communities of Pahoa and Kalapana. Other roads link smaller residential communities (primarily subdivisions) to Pahoa and to the sparse cluster of homes in the coastal community of Kalapana.

The proposed 500 MW geothermal development would be located in lower Puna along the Kilauea East Rift Zone, in the Kapoho/Pohoiki area and parts of the Puna Forest Reserve. The communities closest to the project sites include several subdivisions and the town of Pahoa.

Puna's economy is distinctive for the Big Island in that it lacks major tourism investment and no longer produces sugar; Amfac's Puna Sugar Company ended its sugar operations in 1984. With the end of sugar operations and the consequent release of acreage for other purposes, diversified agriculture has taken on increased importance. Diversified agricultural crops grown commercially in Puna include: papayas, macadamia nuts, bananas, flowers and foliage.

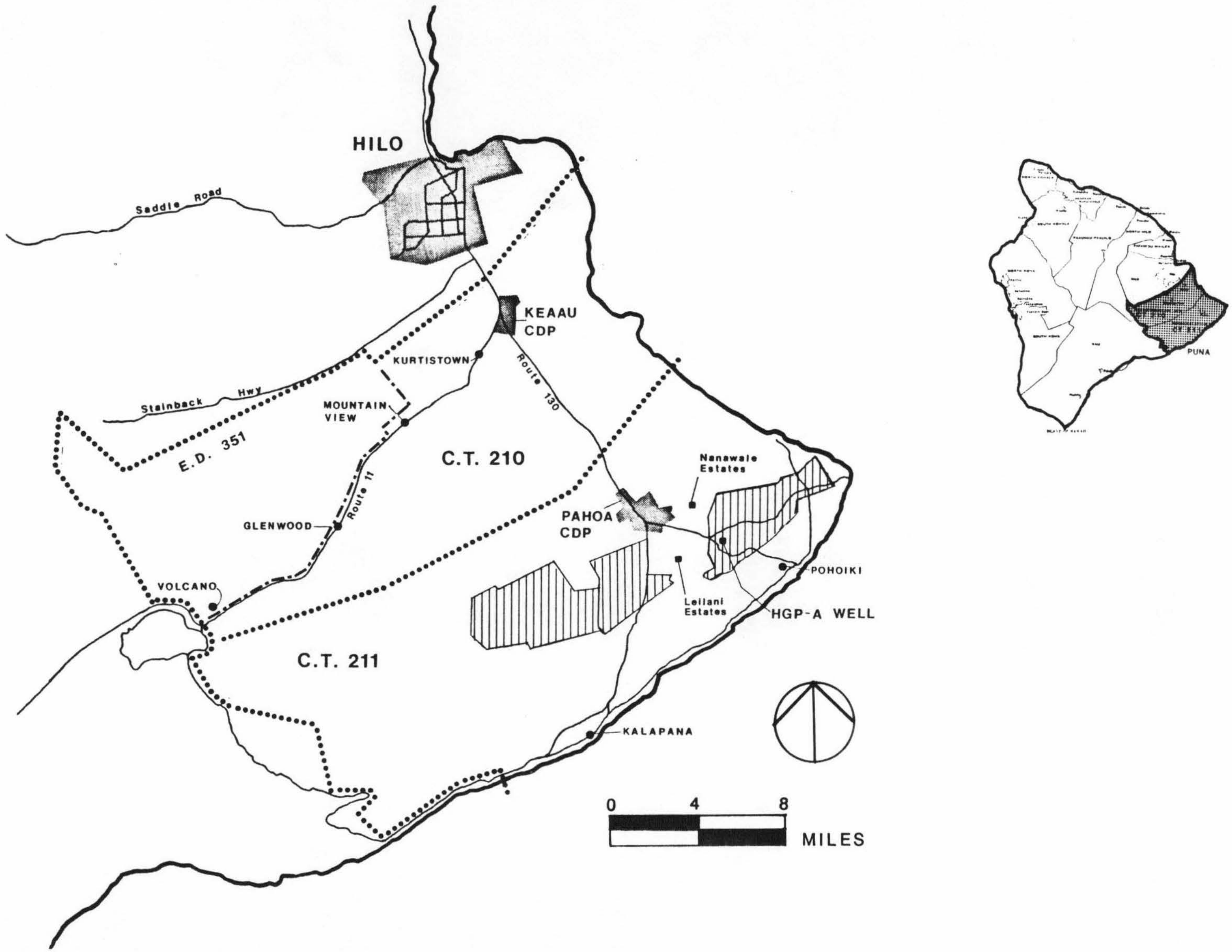


Figure VIII-1

PUNA CENSUS TRACTS AND ENUMERATION DISTRICTS

Commercial and retail activities are found in Keaau, Kurtistown, Mountain View, Glenwood, Volcano, Pahoa, and Kalapana. A regional shopping center has opened in Keaau. The majority of commercial operations in the district are still family-operated enterprises serving the nearby communities.

Industrial activities in Puna have included the processing of agricultural products and the production of energy from bagasse. Until recently, the Puna Sugar mill supplied Hawaii Electric Light Company (HELCO) with power generated by burning wood chips and bagasse. Amfac has withdrawn from power-generating activities in Hawaii County, selling its biomass plant and interest in a geothermal venture (Harada-Stone, 1988a, 1988c).

W. H. Shipman, Ltd. has developed a light industrial park in Keaau. Nearly all lots in the first increment of 19 lots were sold at the park's opening in January, 1988 (Hawaii Tribune-Herald, January 29, 1988). The park includes space for some 300 lots (Bob Cooper, personal communication).

Currently, one small-scale geothermal installation is in place and another is planned in the Kapoho-Pohoiki area. In the lower Puna areas near the existing geothermal sites, major economic uses of the land include diversified agriculture, subsistence agriculture, hunting, and livestock raising. Pahoa is the primary retail center for lower Puna, although it lacks the larger shopping facilities to be found in Keaau or Hilo.

3.0 Demographic Indicators

<u>Population</u>. The State has estimated Puna's mid-1986 population at 18,400 -- suggesting an average growth rate of 7.4 percent per year. Puna's estimated growth in the period 1980 - 1986, was faster than that of all other districts in the state during the same period, except for Hanalei District on the island of Kauai (DBED, 1987a).

Much of the district's recent growth has been taking place in lower Puna (Census Tract 211), which increased its share of the overall Puna population from 26 percent in 1970 to 40 percent in 1980. Data in Table 8.1 indicate a number of changes in the demographic composition of lower Puna's population, including: (a) by 1980, Caucasians had become the largest ethnic group in the district in 1980 (they were fourth in 1970); (b) the educational level of the population rose substantially; (c) the proportion of the population living in the same house five years earlier dropped sharply, while the proportion of residents born outside Hawaii increased; and, (d) the percentage of the population over 65 years of age decreased sharply accompanied by an increase in the proportion of people aged less than five years.

Pahoa, which is located in C.T. 211, is the Census Defined Place (CDP) nearest to the geothermal project site. (The other communities listed in Tables 8.1 to 8.4 are all in C.T. 210, Upper Puna). Pahoa showed no population increase during the 1970s. In lower Puna, the subdivisions, rather than the town, have attracted new residents. Proportionately more ethnic Japanese (43 percent) and foreign-born persons (22 percent) reside in the Pahoa CDP than in the Census Tract as a whole. Pahoa residents in 1980 were less likely to have completed high school than others in lower Puna, and far less likely to have lived off-island.

Labor Force. In both 1970 and 1980, the Puna unemployment rate was higher than the county average, and the labor force participation rate was lower (Table 8.2). By 1980, the Puna unemployment rate was 1.75 times the county rate. More recently, the county unemployment rate has increased, but Puna's rate remains higher than the county average. The State Department of Labor and Industrial Relations (DLIR) estimated Hawaii County's 1986 unemployment rate at 7.6 percent; the comparable figures for lower and upper Puna were 12.8 and 13.5 percent respectively (Francisco Corpuz, personal communication). It should be noted that when Amfac's Puna Sugar Company ended its sugar operations in 1984, about 485 jobs were lost by the end of the shutdown. While many of the Puna Sugar workers lived in Keaau and Hilo, about one-fifth lived in Lower Puna (DLIR, 1982).

Family Characteristics and Income. In 1980, the Hawaii County median family income was 84 percent of the state median figure. As shown in Table 8.3, the median family income for lower Puna ($13,842) was only 72 percent of the 1980 county median ($19,132). The percentage of families below the poverty line in both Puna census tracts was above the county average, but the lower Puna percentage was notably higher than the upper Puna figure.

The Pahoa CDP showed a particularly high percentage of families below the poverty level in 1980. Yet, this area also had a high percentage of families in upper-income brackets, indicating a wide range of incomes.

Compared to both upper Puna and the county as a whole, lower Puna's family structure in 1980 was slightly more weighted toward female-headed households, especially in families with children present.

Housing Stock. Improvements in the availability and quality of housing are visible in the rise in owner-occupied housing and the decrease in substandard housing shown in Table 8.4 (although the proportion of units in Puna lacking plumbing or with relatively few rooms still remained above the county figure).

The 1980 U.S. Census showed the percentage of owner-occupied housing to be higher in Puna than in the county as a whole (Table 8.4). The median value of housing in the district was, however, well below the county median. In lower Puna, the 1980 median value was only two-thirds the county median. Rents, on the other hand, were higher in Puna than in the county as a whole in 1980.

4.0 Life-styles and Values

Puna residents often stress that they like the relatively undeveloped character of the district. Nonetheless, many express concern over the availability of jobs and the limited infrastructure of the district. A 1982 survey sponsored by the State and County showed that residents found that the "best things" about life in Puna were: (a) the area's undeveloped character; (b) the weather; (c) the scenery; and (d) lack of pollution (SMS Research, 1982). Puna respondents to a 1983 survey mentioned both environmental and interpersonal aspects of the district when asked their opinion about the "two best things about living on the Big Island" (Hawaii Opinion, Inc., 1983). Puna residents mentioned "nice, friendly people" more often than any other category, and more often than did people from other districts.

Puna residents sometimes describe themselves as rural, or as persons who have chosen a rural life-style. A "Puna life-style" can involve various ideals and practices: an emphasis on family life, an appreciation for the friendliness and slow pace of life in small communities, the ability of residents with agricultural resources to "live off the land," or to "live in harmony with the land," achieving self-sufficency. Residents' sense of themselves as independent pioneers is in some cases bolstered by the notion that Puna is "the last frontier" (Fluor Technology, Inc., 1987).

The foregoing suggests that Puna residents value easy personal relations and the rural nature of their district. However, their lives and attitudes are more complex than this may suggest.

First, Puna is not as isolated as some other areas on the island. Most residents shop, and many are employed, in Hilo (SMS Research, 1982). Second, many residents report substantial concerns over limited economic opportunities in Puna, and want improvements in roads and government services.

Next, social change and problems are part of life in Puna. Residents' geographic mobility is high. School populations include many new arrivals; in 1986-87, about 600 new students came to the Pahoa schools, and 453 left, while the total enrollment was about 1,700 (Edward Matsushige, personal communication). A government fact-finding group cited local social service providers as finding child abuse, child neglect, and sexual abuse "not uncommon" in lower Puna (Progressive Neighborhoods Program Task Force, 1984). Some of these social service informants feared to make personal household visits in the area.

B. ATTITUDES TOWARDS DEVELOPMENT

1.0 Attitudes Toward Economic Development in General

Hawaii County Attitudes. Residents of the Big Island have consistently favored economic development because of a need for jobs. Big Island respondents were more in favor of growth (68 percent favoring) than others in the state (53 percent favoring, statewide) when asked in a recent survey whether they supported economic growth for Hawaii (Sunderland and Associates, 1987).

Nearly all Hawaii County respondents to the 1984 State Plan Survey (SMS Research, 1984), thought that Hawaii needs more jobs and industry. (For 67 percent of the Hawaii County sample, this issue is "extremely important" -- compared to 55 percent of the respondents statewide.) An earlier survey on tourism found that Big Island residents valued tourism because of the money it brings to the island and because the industry provides needed jobs (Ward Research, 1982).

A concern qualifying Big Islanders' support for economic development is local control. Only 36 percent of the Big Island respondents to the Sunderland survey mentioned above favored state-level decision making on projects affecting one island. Residents of the other Neighbor Island counties were similarly unwilling to support centralized control.

Puna Attitudes. In recent opinion surveys, Puna residents have expressed strong support for economic development. Like others on the Big Island, they favor the creation of new jobs. The closing of the Puna Sugar Company in 1984 and the relatively high level of unemployment in Puna underline this concern. Yet, many oppose industrialization on the grounds that it could change the area into a densely populated, polluted zone. Puna residents have favored diversified agriculture and light industries related to agriculture over other types of economic development (Table 8.5).

The County's planning survey (Hawaii Opinion, Inc., 1983) included questions about economic development "on the Big Island." Puna residents voiced support for diversified agriculture, tourism, and aquaculture. Only about a quarter of those polled in Puna supported either geothermal development or heavy industry.

In the Puna Community Survey (SMS Research, 1982) upper Puna residents tended to support economic development. Residents of the Kapoho-Kalapana area were more apt to be

Table 8.5. APPROVAL OF TYPES OF DEVELOPMENT IN PUNA

Proposed Development	Percent Saying "good for Puna"
New jobs for Puna	93
More diversified agriculture	91
Light industry (fruit drying, hothouses, aquaculture)	83
Improve current roads; build more	78
Build new parks	64
Use sugar or scrub trees for ethanol production	63
Generate electricity from volcano's steam	62
More housing	55
Resort areas, tourism	34
Major industry like manganese nodule processing plant	33
(base:)	(778)

Source: SMS Research (1982)

skeptical or opposed to development. Pahoa residents were more concerned than others with social problems (SMS Research, 1982).

2.0 Attitudes Toward Geothermal Development

Hawaii County Attitudes. Various opinion surveys indicate that, like other Hawaii residents, people on the Big Island recognize Hawaii is heavily dependent on outside sources of energy. Many favor developing alternate sources of energy. Geothermal development is widely supported, although survey respondents are less in favor when it is linked with heavy industrial development in Puna or elsewhere on the Big Island.

In a recent survey (SMS Research, 1987), people were asked to give their opinion of programs to build an undersea cable to send geothermal electricity from the Big Island to Hawaii. The idea of exporting energy to other islands was favored by a large majority of respondents statewide. Most of the 101 Big Island respondents were also supportive:

Very favorable	48.5%
Somewhat favorable	22.8%
Somewhat unfavorable	12.9%
Very unfavorable	6.9%
Don't know	8.9%

In an earlier survey (SMS Research, 1986), a plurality of those asked about a geothermal export scenario supported the idea (Table 8.6). Big Island residents' reasons for supporting or opposing the export of geothermal energy were similar to those of Puna residents. Supporters looked for economic benefits from geothermal development and liked the idea of sharing energy with other islands. Some wanted assurance that the impact of geothermal projects on the environment and on residents' health and life-styles will be limited.

In another survey (Sunderland and Associates, 1987), people were asked whether they generally favored geothermal energy, the resorts of West Hawaii, a spaceport and a papaya irradiation plant. A majority of the 400 Big Island respondents supported geothermal development (77 percent), resorts (74 percent), and the space launch facility (54 percent). Residents of East and West Hawaii alike were similarly in favor of geothermal development.

Over a thousand respondents to the 1983 County planning survey (Hawaii Opinion, 1983) were asked to rank their support for various industries by indicating how, "If you

Table 8.6. RESPONSES OF HAWAII COUNTY RESIDENTS TO THREE GEOTHERMAL ENERGY SCENARIOS

	Scenario 1 Small-scale, local use		Scenario 2 Large-scale, local use		Scenario 3 Large-scale, exporting	
	Puna	Island	Puna	Island	Puna	Island
In favor	66%	65%	43%	47%	37%	40%
Opposed	18%	28%	29%	23%	36%	32%
Depends	14%	19%	23%	23%	21%	21%
Don't know/no response	3%	9%	5%	7%	6%	8%
(base:)	(103)	(227)	(103)	(227)	(103)	(227)

Source: SMS Research (1986)

had ten million dollars to help industries on the Big Island," that money should be divided. Geothermal development ranked sixth (after diversified agriculture, tourism, aquaculture, construction and sugar) for respondents island wide. Island wide, 41 percent of respondents supported "geothermal-related" development. In Puna, only 24 percent of the 117 respondents did so, the same proportion as supported heavy industry.

Puna Attitudes. Although residents of Puna are more likely than others in Hawaii to be critical of geothermal energy development, supporters of geothermal projects have typically outnumbered opponents in surveys. Residents have responded more positively when the idea of geothermal energy development was separated from industrial development in Puna. Many question the need for extensive geothermal development in their district. Yet, many of those who criticize particular projects state their support for geothermal development in principle (e.g., Leilani Community Association, 1978).

A 1986 survey (SMS Research, 1986) asked respondents to evaluate three geothermal energy scenarios: (1) plants near the existing Kapoho facility, producing about 25 megawatts for use by Big Island consumers; (2) plants in Kapoho and the Puna Forest Reserve, producing about 100 megawatts to generate all the power used by Big Island consumers; and (3) plants in Kapoho and the Puna Forest Reserve, occupying a larger area than the plants described previously, producing up to 500 megawatts for export to Oahu. Of the 227 Big Island respondents, 103 were from Puna. Table 8.6 indicates both the Puna responses and the responses of the entire Big Island sample.

In this survey, Puna supporters and opponents of exported energy were about equal in numbers. Economic and environmental factors were mentioned as concerns, but the major issue discussed by both sides was the sharing of resources with outsiders. While energy export could allow the use of resources without promoting widespread industrial development, this argument was not developed by Puna residents.

Residents of other districts were somewhat more favorable towards the second and third scenarios than were people from Puna. While scenarios involving a "large-scale" geothermal development did not win the support of a majority of Puna respondents, a few more supported those scenarios than categorically opposed them. For some on the Big Island, energy export is welcome because the sharing of resources is seen as a value. Puna respondents were likely instead to be unwilling to share, arguing that others should solve their own energy problems.

A 1984 health study in Leilani Estates included questions about attitudes toward geothermal development. Leilani Estates is adjacent to the first successful geothermal well. Residents reported some annoyance due to noise (18 percent of respondents) or smells (14 percent) in the previous year (Anderson and Oyama, 1987). Still, 44 percent favored geothermal development in Puna, while only 20 percent opposed it (Memorandum, B. Anderson to D. Thomas, February 12, 1986).

In 1982, Puna residents were asked their opinions of (1) geothermal energy development alone, (2) energy development with light industrialization, and (3) energy development with heavy industry. The combination of geothermal with light industry gained the strongest support (66 percent of those responding in favor). Twice as many respondents opposed heavy industry (44 percent) as supported this option (21 percent) (SMS Research, 1982).

3.0 Assessment of Community Concerns and Issues

Community concerns and issues deserve study because (1) if controversy and polarization occur in the process of planning a project, these are social impacts of the proposed project; (2) certain issues are difficult to quantify, and the aim of identifying impacts may be served by noting these concerns in the environmental assessment.

Information on community concerns and issues comes mainly from surveys and testimony at public hearings. Surveys can show whether a concern is widespread at a given time. Testimony can provide a detailed account of one speaker's views of an issue. Both sources of information have limitations. The viewpoints expressed at hearings need not be widely shared. Surveys provide a snapshot of opinions that may change over time. Also, different issues have emerged as important for residents when different geothermal futures are discussed.

Puna residents' concerns in relation to geothermal development can be grouped under five headings for analytical purposes:

<u>Economic Benefits</u>. Many in Puna recognize a need for new jobs (Table 8.5). Geothermal development is sometimes supported as a source of employment (SMS Research, 1987). The cost of electricity is also a concern of residents; some favor geothermal energy as leading to stabilized costs for electricity. Several survey respondents see a present and future need for electrical energy in Hawaii. Some mention that residents of some Puna areas do not now have electricity; others support geothermal energy as supplying the power necessary for economic growth (SMS Research, 1986).

Sharing of Local Resources. The idea of energy self-sufficiency is widely supported in Puna and elsewhere on the Big Island (SMS Research, 1986). Geothermal energy is sometimes viewed as a Hawaiian resource to be shared among Hawaii's people. Some Puna residents, however, are unwilling to share with other islands, and see urban institutions -- the State government and energy companies -- as threatening their life-style. For some, then, geothermal energy development and export could bring Hawaii's people together; for others, proposed developments threaten a valued isolation.

Environmental Issues. Survey responses show a widespread concern for the ecology. Consequently, many respondents are willing to support geothermal energy if assured that environmental issues will be carefully addressed. Some residents argue, however, that geothermal development will exhaust natural resources. The possible impact of geothermal sites on forest vegetation and wildlife, particularly the 'io Hawaiian Hawk, has been viewed critically. Opponents of geothermal development have repeatedly expressed concerns that, in the case of an earthquake or similar catastrophe, environmental damage might occur which energy developers could not control or repair (Edmunds, 1987). While many persons are concerned with the environment, there is no evidence that they share all the ecological concerns mentioned by speakers at hearings on geothermal sites.

Impact on Residents. Many residents have questions about possible impact of geothermal development on their own lives. Such as:

- Will their catchment water be affected by fumes or will their livestock be harmed by noises or fumes? (Often a buffer of a mile is requested between project sites and residences).

- Puna subdivision residents, living near proposed electrical transmission lines, have raised questions about potential impacts. One resident, chairman of the Transmission Line Committee of the Puna Community Council, mentions as his concerns (1) health and safety; (2) property values; (3) visual impacts; (4) TV and radio reception; (5) the possibility that additional lines will be strung once an easement for power lines is obtained (Laine, 1987). In his letter, he speaks in favor of "responsible development" that minimizes impacts on residents and existing homes.

- Puna residents have also expressed uncertainty or concern over several potential impacts. Noises and smells associated with geothermal production are sometimes thought to affect wide areas. Residents question whether their health may be affected by fumes. One issue is that geothermal development could bring population increases. Some note that area residents supplement their diets by hunting in forest areas that will be affected by geothermal development.

- In surveys (SMS Research, 1982, 1986), Puna residents rarely mentioned religious reasons for their attitudes toward geothermal development. In public hearings, though, some Hawaiians have testified to their worship of Pele and their sense that any geothermal development in Puna amounts to sacrilege. The Puna Hui Ohana report (1982) further proposed that geothermal development could change Hawaiians' attitudes towards persons, nature, and the supernatural.

  In February 1988, advertisements urging people to oppose geothermal development on the Big Island appeared in Hawaii and mainland newspapers. The Pele Defense Fund opposed geothermal drilling partly as violating Hawaiians' religious beliefs and as a step towards industrializing the Big Island.

4.0 Relative Importance of Different Concerns to Geothermal Development

The relative importance of different concerns for members of the community at large has been indicated in two surveys (SMS Research, 1982, 1986). The 1982 survey asked Puna residents' opinions of three geothermal futures (electricity production alone, with light industry, and with heavy industry). The survey also probed for the <u>reasons</u> behind residents' opinions. Those reasons can be roughly grouped as economic, environmental, social, and other.

Overall, Puna survey respondents mentioned economic issues most often, then environmental issues, and finally social and other issues about equally often. Kapoho-Kalapana residents were much more likely to mention environmental and economic issues than social and other issues. Keaau residents -- in an area relatively far from the geothermal sites, where development has depended on sugar production and proximity to Hilo -- placed far more weight on economic issues than any other factors. (These findings were reached by combining data from tables in SMS Research, 1982.)

The 1986 survey also asked people's opinion of three scenarios and the reasons for their opinions. The three scenarios were not the same as in the 1982 study, which lacked an "export to Oahu" scenario. Instead, they were the scenarios listed in Table 8.6: (1) small-scale, local use; (2) larger-scale, local use; and (3) larger-scale, export.

Respondents' reasons for their opinions -- whether those opinions were positive, negative, or "it depends" -- can be grouped as:

- o concern with <u>shared use of local resources</u> (e.g., for opponents, an unwillingness to share local geothermal resources with outside areas, or, for supporters, a sense of duty or desire to share) -- a category of concern which did not emerge so strongly in the 1982 survey;

- o concern with <u>energy</u> itself (e.g., interest in alternate energy, wish to minimize oil dependence);

- o <u>economic/cost</u> concerns (e.g., jobs, or the cost of electricity);

- o <u>environmental</u> concerns (e.g., with forest resources, or concern about fumes and health impacts);

- o <u>other</u> reasons (e.g., vague or general ones).

(It should be noted that some of the issues which were frequently discussed in public hearings rarely emerged in surveys of the general public. A listing of verbatim comments in the original survey report shows that even the miscellaneous "other" category rarely included any discussion of issues such as religious concerns or property values.)

Table 8.7 summarizes the most frequent reasons expressed by respondents in both Puna and the rest of the island for the opinions they expressed about all three geothermal scenarios. It may be seen that -- for the two non-export scenarios -- geothermal development supporters in both Puna and the rest of the island focused primarily on energy needs and secondarily on economic/cost factors. Both opponents and the undecided focused primarily on environmental (and health) concerns.

The issue of whether or not to share local resources emerged as a much greater consideration for the export scenario. The minority of Puna respondents supporting energy export to Oahu stressed a desire to share resources as the second most frequently stated reason. Opponents of export in both Puna and the rest of the island were likely to specify their unwillingness to share local resources (and/or their preference to let Oahu solve its own energy problems) as a major rationale for their positions.

Table 8.7 PRINCIPAL REASONS GIVEN FOR SUPPORTING OR OPPOSING VARIOUS GEOTHERMAL DEVELOPMENT SCENARIOS, BY PART OF BIG ISLAND

Puna

	Scenario 1 (25 MW, only for Big Isle)	Scenario 2 (100 MW, only for Big Isle)	Scenario 3 (500 MW, for export to Oahu)
SUPPORTERS (Why?)	Energy Economy/Cost	Energy Economy/Cost	Energy Sharing (Yes)
OPPONENTS (Why?)	Environment	Environment Other	Sharing (No) Environment
"IT DEPENDS" (What does it depend on?)	Environment Economy/Cost	Environment Other	Other Environment

Rest of Island

	Scenario 1 (25 MW, only for Big Isle)	Scenario 2 (100 MW, only for Big Isle)	Scenario 3 (500 MW, for export to Oahu)
SUPPORTERS (Why?)	Energy Economy/Cost	Energy Economy/Cost	Economy/Cost Energy
OPPONENTS (Why?)	Environment Energy	Environment Other	Environment Sharing (No)
"IT DEPENDS" (What does it depend on?)	Environment Economy/Cost	Environment Other	Environment Economy/Cost

Source: SMS Research (1986) (and additional analysis for this report by Community Resources, Inc., 1987)

The SMS analysis of the findings, however, suggested that apparent unwillingness to share resources with Oahu was still actually rooted in environmental concerns, in that opponents objected to paying environmental costs for Oahu's energy benefits.. This analysis would fit with observations about energy production controversies around the country, in that conflict typically involves perceptions of localized costs borne by relatively few people around the production site vs. widely dispersed benefits for residents far from the site.

C. SOCIAL IMPACTS

1.0 Overview

The social impacts of the project follow in part from physical and economic changes, in part from residents' perceptions of possible changes, and in part from processes of anticipating and reacting to such changes.

As shown on Table 3.3, during the construction phase, geothermal power is expected to directly support 575 people and 215 homes, and directly and indirectly support a total of 1,430 people and 530 homes. Upon full operations, 480 people and 180 homes would be directly supported, and 1,570 people and 580 homes directly and indirectly supported.

The project's social impacts would be greatest during the construction phase, but would diminish over time. The more significant potential impacts on particular areas are:

o <u>Homes Near Project Sites</u>.

People living close to the geothermal sites -- within about two miles of power plants or wells -- could experience annoyance from noise and other physical impacts when construction occurs near them. (This impact would not last throughout the entire construction phase, but for a short time only, when nearby facilities are being built.) The result could be a sense of intrusion, and a loss of peace and isolation. Residents' concerns about safety could increase if heavy equipment often blocks roads leading out of their immediate area.

o <u>Pahoa and Puna Subdivisions</u>.

The hiring of over 200 construction workers would bring economic benefit to Lower Puna. If current residents make up the bulk of workers hired, few further impacts would be expected. If construction workers largely come from Hilo, then traffic within the Puna area would increase, possibly leading to congestion and delays. If many new hires move into Puna at one time, housing prices (rentals) and demand for public services in limited supply could rise. These impacts would be of short duration and would lesson considerably after construction is completed.

o <u>General Puna Population</u>.

Three potential impacts are likely to affect members of the general population:

- Political Conflict During Planning and Permitting: Feelings will run high during debates over the project. Since mechanisms for mediation and planning to benefit the community are available or being developed, such conflict could result in coordination of efforts by the community, State, and developer.

- Perceived Changes in Character of Area: Many residents are likely to see the rural, peaceful character of Puna as harmed by geothermal development. Debates before construction can increase this expectation. Construction impacts, including noise, the sight of drilling rigs and heavy, slow-moving equipment, will reinforce this perception for some people. Later on, this perception is likely to weaken. It may be minimized if restrictions on access to areas in the geothermal subzones are limited and unobtrusive.

- Psychological Apprehension: Some residents view geothermal development as likely to increase risks of hazardous events. This apprehension is likely to diminish when and if geothermal operations turn out to be less intrusive and hazardous than feared.

All the impacts identified above can be mitigated. Residents' concerns with transmission lines linking the project and the undersea cable are not discussed here, as they are outside the scope of this environmental review.

All of the major social impacts except psychological apprehension will vary in expectable ways through the project's phases. Psychological apprehension is discussed separately while other potential impacts are discussed in relation to the development stages.

2.0 Planning and Permitting Phase: Political Conflict

The major social impact of the development period prior to construction is political debate. Concern will arise over anticipated changes in area character. As discussed previously, community opinion regarding large-scale geothermal development is mixed, so debate and opposition to the project are expected. The impact of community discussion of geothermal development will be limited, however, because extensive discussions have already occurred.

Debates over geothermal development have gone on for over a decade on the Big Island. Official hearings and a court case have provided the major arenas for debate. Several outcomes of past discussions will affect future ones:

- o Puna residents have detailed knowledge of geothermal operations (Puna Hui Ohana, 1982; Edmunds, 1987).

- o Past efforts to gain and evaluate information about developers' plans have left some residents dissatisfied and mistrustful of developers' claims (Edmunds, 1987).

- o Some residents have come to view large-scale geothermal development as a taking of local resources for the benefit of more developed areas, and at the risk of developing Puna. Also, some see inequities in the prospect of large-scale generation of electricity in a region where electrical service is often absent or judged expensive and unreliable (SMS Research, 1986).

- o Interpersonal and organizational linkages among the community, developers and State agencies have been created (for example, the DBED Geothermal Advisory Committee); these should facilitate the discussion of new initiatives.

- o Mediation and hearing procedures have been developed as part of the permit process for geothermal development. Mediators have developed strategies and draft documents that can be adapted to new situations (Dinell and Goody, 1988).

- o Baseline studies have been made of air conditions, and standards for the abatement of emissions have been proposed. Emission control devices have been added to the HGP-A plant (Dinell and Goody, 1988; DPED, 1983). These show that controls and standards can be worked out in response to community concerns.

At a November 1988 community meeting in Puna sponsored by the State Department of Business and Economic Development (see Appendix A), State officials, consultants, and developers answered community questions about the project. One issue raised by members of the community -- a need for a "Master Project Plan" clarifying project timelines, uses of the power generated, implications for community growth, and plans to avoid social disruption -- could benefit the Puna community.

Proposals for new geothermal development are likely to be followed by new efforts to organize opposition, to advance local interests, and to promote dialogue between opposing viewpoints. Feelings will run high. Nonetheless, mechanisms for finding common ground are available.

3.0 Construction Phase

Major social impacts of the project in the construction phase will depend on both physical impacts of the project and employment patterns.

Physical Impacts.

During drilling and construction, potentially intrusive impacts are:

- o The noise from well-drilling could be considerable near construction areas;

- o With venting, steam bearing hydrogen sulfide in perceptible concentrations may sometimes escape;

- o Well-drilling equipment would be far more visible than the eventual wells and plants; and

- o Heavy equipment would frequently travel on Puna roads.

Employment.

Table 8.8 shows a timetable for both the construction and operational employment given in Table 3.3. As discussed in Part III of this report, total on-site employment will increase to a peak of 434 jobs in the 14th year of the project, and then fall to a steady 200 jobs for the rest of the operational phase.

Employment patterns generate social impacts if they involve many people or sudden changes in the number employed. The number of jobs involved in the project is large for Puna; therefore social impacts could follow from the hiring of 240 workers as construction begins.

In 1980, the civilian labor force of Lower Puna (Census Tract 211) included 1,635 persons, of whom 11.9 percent were unemployed (Table 8.2). Project employment would thus reach a level equivalent to one quarter the region's 1980 workforce. The direct population impact of the project is calculated in Table 8.8. This would be expected to grow to over a thousand persons, then to level off at just under 500. The maximal direct population impact would amount to 22.2 percent of the 1980 Lower Puna population (shown in Table 8.1). The population impact would probably be smaller than calculated here, because some workers would come from the existing population, and because the area population would be larger at the time of impact. The population of Puna District is growing rapidly -- between 1980 and 1986 it increased at an annual rate of 7.4 percent (DBED, 1987b).

Indirect employment and population impacts are not considered here. Impacts due to indirect and induced spending would more likely be felt in the Hilo area, where Puna residents and businesses make most of their purchases.

Table 8.8 EMPLOYMENT AND POPULATION IMPACT OVER TIME

PROJECT YEAR	EMPLOYMENT AT THE PROJECT: Construction	Operations	TOTAL	POPULATION IMPACT (1)
1	240	0	240	576
2	240	0	240	576
3	240	0	240	576
4	240	17	257	617
5	240	34	274	658
6	240	51	291	698
7	240	68	308	739
8	240	85	325	780
9	240	109	349	838
10	240	126	366	878
11	240	143	383	919
12	240	160	400	960
13	240	177	417	1001
14	240	194	434	1042
15	0	200	200	480
16	0	200	200	480
17	0	200	200	480
18	0	200	200	480
19	0	200	200	480
20	0	200	200	480
21	0	200	200	480
22	0	200	200	480
23	0	200	200	480
24	0	200	200	480
25	0	200	200	480

(1) Direct population impact = project workers and families

SOURCE: Assumptions derive from Part III, Economic Analysis

1980 conditions cannot be projected to the time of peak project employment, but it is clear that project employees and their families will constitute an important part of the population, unless nearly all live outside Puna.

Project employment patterns can have very different impacts, depending on who is hired and where they live. Three scenarios will be considered:

- o Few Lower Puna residents are hired, and new hires continue to live outside Puna -- a "Commuter Scenario";

- o Few Lower Puna residents are hired, but many new hires come to live in Lower Puna -- a "Newcomer Scenario"; and

- o Many Lower Puna residents are hired, along with some nonresidents, and some of those newcomers make their homes in Puna -- a "Mixed Scenario."

The project would offer stable employment for both construction workers and operational workers. As a result, many workers would probably seek homes near the job site. Puna subdivisions offer land at low prices, so many project workers could afford to invest in home sites and home construction. This means that the Commuter Scenario would be likely only for a brief time early in the construction phase.

Much of the project's work force could be recruited from current Lower Puna residents. Many of the jobs created by the project could be performed by members of the existing labor force (DPED, 1982). Also, because Lower Puna workers reported commuting times in 1980 well over the County average (see Table 8.2) -- some would probably prefer to work in the area rather than commuting to Hilo or West Hawaii. After the closing of Puna Sugar, unemployment and underemployment were high in the area -- although Big Island unemployment has been reduced lately, due to hiring at West Hawaii resorts.

The Newcomer Scenario also appears unlikely for the reasons given above. The Mixed Scenario combines the most likely hiring and residence patterns.

Impacts on Nearby Residential Areas

The Geothermal Resource Subzones (GRS) are largely forested; the areas have few inhabitants. Some residential areas would, however, be close enough to be affected by construction activities. These would include Leilani Estates, Nanawale Estates, and a few homestead areas. (One small subdivision, Lanipuna Gardens, is inside the Kapoho section of the subzone.)

The major concerns of Puna residents living near the subzones involve personal safety and change in area character. No threats to nearby residents' safety would be anticipated from the development; the character of the immediate area, as perceived by the residents, could be affected.

The closer a given household is to major geothermal structures, the greater the possible impact. That impact would be of short duration -- at most a year or two -- as activities in the construction phase would extend over a large area, and would be near any given home only for a limited term.

During drilling and construction, nearby residents' perceptions of the immediate area are likely to change:

- Construction noises and smells, however infrequent, may be experienced as intrusive and annoying;

- Residents of outlying areas would no longer be able to see their homes as isolated in the forest; and

- The obstruction of roads by slow-moving vehicles could raise concerns about evacuation in case of emergencies.

Drilling activities would continue after the initial construction period, as replacement wells are dug (Part III). The impacts noted here would then reoccur in particular areas, for short times during the life of the development.

A decrease in the feeling of peace and isolation near project construction sites would be unavoidable. The intrusive impacts reviewed here could be controlled, however, through use of abatement technology. The negative social implications of project construction could be offset, in part, by economic benefits and improvements in infrastructure.

<u>Impacts on Pahoa and Lower Puna Residential Areas</u>

Traffic impacts on county roads and the town of Pahoa could be moderated during construction, if the movement of heavy equipment is scheduled to minimize congestion. Trips by workers in both phases would mainly be in the opposite direction to the major traffic pattern of the region. These would not be expected to appreciably affect levels of service on Puna roads. If traffic congestion is identified as a problem, then car pooling or the bussing of workers to work sites could be suggested.

Social consequences of project construction employment for Puna residential areas fall under two headings:

- Community Change: Major energy projects have been thought to cause disruptions of small communities. In "Boomtowns" created by large-scale energy developments, the arrival of many newcomers has, some argue, brought tensions between new arrivals and settled members of the community, mental health problems, and demands for services far greater than what local communities can supply (see England and Albrecht, 1984; Krannich and Greider, 1984 for summaries and analysis). "Boomtown" conditions resulting from the construction and operation of the proposed 500-MW geothermal development would be unlikely to occur in Lower Puna because:

  - Lower Puna is not an isolated community with little experience of change -- the population increased threefold during the 1970s, and the area has experienced demographic and social change linked to the closing of Puna Sugar and to the presence of an illicit economy -- marijuana growing -- in the region;

  - With much land in the subdivisions unoccupied, newcomers would not be expected to adversely affect land prices; and

  - Because few County services are provided to the subdivisions, the arrival of newcomers would not limit others' access to services that are not now available. (Increased population would in fact make the provision of services more cost-effective for the County, and could improve residents' chances of obtaining them.)

  Population increase could, however, add to the existing demand for services now available in limited supply (e.g., space in the crowded Pahoa public schools), and could increase demand for housing, especially rental housing.

- Housing. In 1980, Lower Puna vacancy rates were below the County average (Table 8.4) and the total number of rental units was slightly over 400. Under the Newcomer Scenario, if such conditions persist, housing prices could increase sharply and some long-term residents could find affordable rental housing increasingly hard to obtain. Under the other two scenarios, the impact of the project on housing prices would be far less severe.

  The construction workforce would essentially all begin work at one time. Under the Newcomer Scenario, then, a sudden increase in demand for housing could be possible in the first year of the project. (Demand for housing by immigrant workers could be met more easily from the larger housing stock in the Hilo area -- leading to the Commuter Scenario -- until construction employees find or build homes and move into the Puna region.) Under the more likely Mixed Scenario, housing prices would probably be affected at the beginning of the project, but this effect should be short-term.

Short-term impacts are most probable at the beginning of construction. The existing community would include members who oppose geothermal development or who are uncertain concerning risks it may pose. The sudden arrival of a new workforce and workers' families could create social tensions at a time when tensions due to political conflicts still remain.

Under the (most likely) Mixed Scenario, the recruitment of a high proportion of the workers from the local population would minimize impacts due to the arrival of many newcomers. Positive impacts on the local economy would affect many residents. Newcomers would come to Puna, but they could be integrated into some local communities without great difficulty.

<u>Perceived Character of the Puna Region</u>

For many of the residents who value Puna's rural, undeveloped character, the development could be seen as a threat to "the Puna way of life." The project could involve changes in some residents' life-styles and, for short periods, potentially adverse conditions near the exploration areas; however, it need not pose a grave threat to Puna as a rural area and to "country" life-styles in the region because:

- o The impact of construction activities on nearby residences would be relatively short-term in any one area;
- o After the major construction equipment is on-site, heavy equipment would travel on roads leading to the subzones much less frequently; thus, most Puna residents would rarely see evidence of construction construction activity; and
- o Many construction workers are likely to be members of the community.

Perceptions of regional change, then, may be short-term.

4.0 Operations Phase

Potential social impacts on nearby areas during the operational phase follow in part from the perception of physical impacts of operations. Noise, smells and traffic impacts of operations would be relatively minor, in comparison to construction phase impacts. Visual impacts would probably increase -- overhead power transmission lines could be visible from points along Routes 130 and 132 in and between the subzones. In most cases, however, the road runs through dense vegetation which camouflages the geothermal facilities. In the Kapoho GRS, however, transmission lines would probably be visible above fairly open terrain, and would constitute a notable addition to the landscape. (A visual impact analysis of the conceptual geothermal development is presented in Part VII of this report).

As construction ends and all of the geothermal facilities are in operation, employment on the project is projected to decrease by over 200 jobs. This change would be foreseen years ahead so local entrepreneurs and community planners can time new projects to take advantage of the highly experienced labor force likely to be available in project year 15.

Employment in operations and maintenance is projected to slowly increase until year 15, and then remain stable. With no sudden change in such employment, it is not expected to have distinct social consequences beyond contributions to the area economy.

<u>Impacts on Nearby Residential Areas</u>

Potential social impacts of geothermal operations for nearby residents can be grouped under three headings:

o Concern over Safety. Nearby residents are likely to be concerned about safety issues, although the geothermal development would be engineered to meet safety standards. Designing the facilities to minimize auditory, visual, and olfactory impacts would help to alleviate this concern, in concert with mitigations noted at the end of this Social Impacts Section.

o Residents' Satisfaction with the Immediate Area. The improvement in ambient conditions when construction is completed -- e.g. noise -- could help residents adjust to the presence of geothermal operations in their area. If power transmission lines are visible from homes, however, perceptions of neighborhood character could be adversely affected.

o Land Values. An anticipated decrease in land values due to geothermal development was singled out by one resident as a serious impact (M. Heuer, <u>In</u> BLNR, 1986a). Such a decrease is <u>not</u> a likely result of the project. A study of the impact of geothermal development on housing and land values (DAHI, Appendix D) suggests that only properties located within 835 feet of power plants would lose value. It is not expected that residences would be located within this range. With state-of-the-art abatement technology, any emissions affecting property outside of this range are expected to be negligible.

In summary, project design features, which are required to meet air and noise standards, would also be expected to minimize the development's impact on land values.

Pahoa and Lower Puna Residential Areas

The potential impacts discussed previously for the construction phase (changes in employment, housing demand, and some social tension between existing and new residents) would not be expected to persist into the operational phase.

Newcomers in specialized positions, with more education than many in Lower Puna, would likely become participants in the local community. Such newcomers in other areas have tended to value the protection of the local environment and local values (Schnaiberg, 1986). These newcomers could be like many current Puna residents who view themselves as "urban refugees."

Community life-style would not be expected to change greatly over time. Puna residents tend to view themselves as living a rural, uncrowded life-style. They uphold ideals of living off the land or in harmony with the land. Many oppose industrialization. There is no reason to expect geothermal workers, whether current Puna residents or immigrants, to have very different views.

Perceived Area Character

During the operational phase, the scale of the development, more than the details of its operations, would give some residents a sense of regional change because:

- o The development would involve plants, pipelines, well fields, roads and power lines extending more than ten miles, from the Middle East Rift to the Kapoho-Pohoiki area, in a region where no such large-scale land uses have existed;
- o Some areas that are now protected could be developed for the project; and
- o Public access could be restricted -- to a greater or lesser extent, in more or less obtrusive ways -- to forested land now used by a few and seen by many as part of Puna's "open spaces."

The impact of the development on Puna's general character would, however, be limited. As noted earlier, the visual impact of the wells and power plants is expected to be slight and the development's obtrusiveness could be minimized by proper design and community interaction. Over time, residents would also see that geothermal development does not necessarily lead to industrialization because:

- o The project is unlikely to generate any further uses of geothermal energy in Puna. Should such uses eventually develop, they would be limited to ones channelling direct heat from steam or hot water; and

- o In the unlikely event that additional operations capitalizing on the availability of geothermal energy are eventually built, these would probably involve food processing. Hence the only possible eventual spin-off of the project would expand markets for local produce, supporting diversified agriculture in Puna.

5.0 Psychological Apprehension: Perceptions of Risk

Perceived Risk and Geothermal Energy

In Puna, geothermal operations have been perceived by members of the public as posing health risks (Edmunds, 1987; M. LaPlante, M. Heuer, and C. St. John In BLNR, 1986a). Monitoring studies have not provided evidence to support this claim (Anderson and Oyama, 1987). Still, residents' testimony amounts to evidence of a psychological impact.

The extent of perceived risk associated with geothermal development in Puna beyond the experimental stage cannot be measured. Nor is it known whether this impact might diminish over time, as geothermal installations become known and accepted features in the Puna landscape.

The American public often perceives risks connected with large energy developments as great, even when experts assert that the risks are few or limited (Allman, 1985; O'Riordan, 1983; Thomas, et al., 1980). When the public is informed about experts' views, public concern about risks may continue or increase, rather than lessen (Morgan, et al., 1985).

Uncertainty concerning the level of risk also contributes to public perceptions of risk (Slovic, et al., 1982). Since large-scale geothermal development is new to Hawaii, many residents are likely to experience such uncertainty.

Volcanic Activity and Perceived Risk

In some Puna residents' views, the relation between volcanism and geothermal development is perceived as threatening (M. La Plante, R. Warshauer, P. Heuer In BLNR, 1986a; SMS Research, 1986; Edmunds, 1987). Emissions, eruptions, and lava flows may be seen as related to geothermal development, even when no causal link is demonstrable -- as one survey respondent said, "The volcano would blow the whole island up (if geothermal development took place). Madame Pele would be angry" (SMS Research, 1986).

In the abstract, the hazards of volcanic eruptions are classified by Americans in much the same terms as are used for nuclear energy plant accidents (Cvetkovich, 1985). Reactions to actual eruptions and nuclear accidents are, however, very different (Paul Slovic, personal communication) -- many people approach eruptions, rather than flee them.

If geothermal operations are associated in the public mind with volcanic eruptions, people's concern about <u>potential</u> dangers is likely to be higher than it would be near conventional energy plants. People's responses to <u>actual</u> incidents are likely to be relatively calm.

D. MITIGATIONS

Many of the impacts noted in this Section are expected to be less than anticipated -- in other words, the development would mitigate those impacts through the use of state-of-the-art abatement technology, and through careful planning of sites and routes.

Further mitigations include community dialogue and information programs, economic benefit for the Puna community, and steps to make the development unobtrusive and compatible with residents' legitimate uses of Puna forest areas.

1.0 Community Interaction Programs

The State has already begun a dialogue with the Puna community. Such dialogue can do much to mitigate perceptions of risk and regional change by: (a) offering information in response to residents' questions and concerns; (b) identifying ways to mitigate annoyances and difficulties during the construction process that best meet the needs of residents; and (c) working out a Master Plan to coordinate project development, community growth, public services, and infrastructure -- the State and developers helping the community to anticipate changes and to minimize problems of growth.

Settings for community dialogue include public meetings called by State and County agencies, meetings of local organizations, and informal encounters and meetings of developers' representatives with residents. Further community relations efforts to offer the public reassurance could include:

- o A 24-hour telephone "hotline" on which area residents' complaints are logged, along with development staff available at all times to respond to questions and complaints;
- o Educational programs about geothermal energy and volcanism;
- o Maintaining a seismic monitoring station in Lower Puna, and providing information about seismic activity noted; and
- o Developing and demonstrating contingency plans for geothermal plants in the event of eruptions or lava flows, to show the public that geothermal development does not make catastrophes less controllable.

In addition, community outreach programs can be extended to monitor and alleviate social problems involving newcomers brought by the project.

2.0 Benefits for the Puna Community

Perceptions of benefit are important in reducing perceived risk (Slovic, <u>et</u> <u>al</u>., 1982). Accordingly, the provision of electrical service or employment to residents of Puna can be considered an appropriate response to the problem of risk perception.

Sharp increases in housing prices and demand for public services were noted as possible under the "Newcomer Scenario." To avoid these impacts, the project's developer can:

- o hire construction workers locally;
- o conduct community information campaigns to encourage qualified workers who live in Puna or who can return to homes in Puna to apply for construction jobs; and
- o if necessary, consider providing housing for workers or transport (by car pool or bus) between outlying residential areas and work sites.

3.0 Restriction in GRS Areas

The longer-term impacts of the project can be experienced as minor annoyances or major intrusions in residents' experience of their region, depending on:

- o The distance from public roads of power plants and sources of noise and odor due to geothermal operations;
- o The extent of the area which would be restricted from community access and the length of time that access would be barred; and
- o Whether or not fences and other signs of restricted access are highly visible from roadways -- fence materials and coloring could be chosen to blend in with the surrounding forest and to minimize the appearance of industrial development.

The less noticeable the project is, the less disruption of regional character is to be expected. Also, through community dialogue, some members of the community can come to recognize that geothermal operators are concerned for the environment and residents' safety.

E. CONCERNS OF RESIDENTS OF NATIVE HAWAIIAN ANCESTRY

This section deals with a wide range of issues that have been mentioned as important for persons of Hawaiian descent in connection with geothermal development. Concerns and sensitivities are acknowledged here. The actual impact of geothermal development in relation to most of the concerns noted here cannot be determined from the available sources.

Some Hawaiians (Puna Hui Ohana, 1982; Aluli, In Uprichard, 1988) expect geothermal development to affect people of Hawaiian descent in special ways. In some cases, anticipated impacts depend on reactions of persons and gods to geothermal development. In other cases, legal issues of great concern to Hawaiians and to the State are involved. In this section, these issues are described in order to acknowledge the concerns and sensitivities surrounding geothermal development.

The major sources of information about Hawaiians' concerns regarding geothermal development are a study done in Puna in the early 1980s and the arguments presented by followers of Pele such as E. Aluli and P. Kanahele in opposition to geothermal development.

The Puna Hui Ohana study described the activities and concerns of Hawaiians in Puna. It drew on interviews with key informants in the community and on a survey of most adult Hawaiians in lower Puna.

The Pele practitioners argue that geothermal development will have negative impacts on their religion, psychological state, and identity, and on the Big Island generally (Aluli and Dedman, 1985; E. Aluli and P. Kanahele In BLNR, 1986a; Tanji, 1987).

1.0 Hawaiians in Puna

The Puna Hui Ohana (1982) identified 413 adult Hawaiians residing in lower Puna in the early 1980s. They surveyed 85 percent of that population. The surveyed families accounted for nearly 1,000 inhabitants of Puna. The average age of the persons in those families was 25.4 years.

The Puna Hui Ohana study described the activities and concerns of Hawaiians in Puna. It drew on interviews with key informants in the community and on a survey of most adult Hawaiians in lower Puna. Most of the Hawaiians surveyed lived some miles from the GRS, in Hawaiian Beaches (42.5 percent), Pahoa (21.9 percent) or Kalapana (18.8 percent). Although many lived in relatively new subdivisions, they usually had lived a long time in Puna. The average length of residence in Puna was 22.4 years (for the entire sample).

Most respondents did not report extensive use of the Hawaiian language or involvement in <u>hula</u>. A majority said they consumed traditional Hawaiian foods and used traditional medicines. Most respondents reported involvement in traditional subsistence activities -- fishing, shoreline food collecting, and food gathering. The gathering of medicinal plants and maile was practiced by many, as was hunting. Commercial involvement in these activities was rare.

Since the 1982 survey was published, several Hawaiians have argued that development, especially geothermal development, is improper in a region belonging to the goddess Pele. (Pele is associated with volcanic activity.) These persons, who recognize relationships to Pele based on family ties or worship, became known as the Pele practitioners. A group of them have established the Pele Defense Fund, which carries out legal and public relations work.

Issues raised in the Puna Hui Ohana survey and in the arguments made by the Pele practitioners may affect a larger population of Hawaiians. Hence the Hawaiian population discussed in this section is not necessarily limited to Hawaiian residents of Puna or the Big Island.

2.0 Impacts Anticipated by Hawaiians in Puna

The Puna Hui Ohana survey respondents saw geothermal development as having large-scale consequences. Some impacts were expected by many respondents to be good or bad. In other cases, the response was mixed, with many respondents expecting negative impacts, and a few more respondents expecting positive ones:

GOOD	NEITHER GOOD NOR BAD	BAD
Economy	Social Conditions	Hawaiian Culture
	Community Closeness	Historical Sites
	Employment	Traditional Religion
		Hunting, Fishing, Gathering
		Traffic
		Agricultural Land
		Land Taxes
		Physical Environment
		Quakes, Eruptions
		Plants, Animals

Some 40.2 percent of the respondents viewed the overall impact of geothermal development as bad, and 32.5 percent judged it as good (Puna Hui Ohana, 1982).

Geothermal development was seen as a possible source of jobs, but many Puna Hawaiians doubted whether Hawaiians would get such jobs. One theme in their comments was that it was unlikely that a high technology field such as geothermal would have room for relatively unsophisticated Puna residents of Hawaiian ancestry.

Both the authors of the Puna study and many of their informants stressed the importance of the land for Puna residents of Hawaiian ancestry. The long list of anticipated negative impacts, most of which have to do with the occupation of the land by a new development, underlines the importance for Hawaiians in Puna of respect for the land.

3.0 Hawaiians Claims to Land and Mineral Rights

The question of who is to profit from geothermal development also affects Hawaiians. Legal rights to the new resource must be defined. These rights raise political issues, since the State's position on "ceded lands" is perceived by some Hawaiians as an indication of the extent to which the State recognizes or denies Hawaiians' rights (Ward, 1988).

The ownership of geothermal resources was clarified by the Legislature in 1974 (Act 241, Hawaii Session Laws), when it held that geothermal resources are minerals. Mineral rights on most of the land in Hawaii are reserved for the State (Kamins, 1979a, 1979b). Hawaiians may still have a special interest in the State's revenues from geothermal development. If geothermal revenues are part of the "ceded lands" trust, then the State must dedicate 20 percent of those revenues for Native Hawaiians (Kamins, 1980; Ward, 1988).

"Ceded lands" are public lands that were transferred from the Republic of Hawaii to the U.S. Government at Annexation in 1898. These lands were defined, in the Newlands Resolution of 1898, as a trust held for the people of Hawaii, unlike other Federal government lands. When these lands were returned to the State of Hawaii in 1959, the State took on the responsibility to act as trustee for its people.

The 1959 Act identified five purposes for which revenues from the land are to be dedicated. One of those purposes is "the betterment of the condition of native Hawaiians." In practice, this means that 20 percent of the revenue would go into a trust administered by the Office of Hawaiian Affairs (Ward, 1988). ("Native Hawaiian" is defined by Act of Congress as limited to persons of 50 percent or more Hawaiian ancestry.)

The "ceded lands" clause deals with the State's title to most State-owned land. Whether some or all mineral rights are part of the "ceded lands" trust is a complex legal issue.

Half the Puna Hawaiian respondents thought that Native Hawaiians should receive income from geothermal development (Puna Hui Ohana, 1982). Kamins (1979a, 1980) however cites precedents and reasons for holding that the State owes nothing to Hawaiians or Native Hawaiians from leases for geothermal development.

For some Hawaiians, if a share of the income from geothermal leases is not reserved for Native Hawaiians, the result would be a taking of resources without compensation to rightful claimants.

The State administration is working with an Office of Hawaiian Affairs task force to resolve problems associated with public lands trusts. The question at issue here is a broad legal one with a special application to geothermal development, rather than a problem raised specifically by such development.

4.0 The Pele Practitioners

In a submission to the Board of Land and Natural Resources, Aluli and Dedman (1985) view geothermal development as "an obvious and profound affront to Pele." They argue that Pele is a living goddess. They oppose geothermal development on the grounds that it threatens:

- Pele, and Hawaiians' relationship to the goddess;
- Hawaiians' relationship with the land; and
- Hawaiian identity.

These points were linked in testimony presented by a Big Island <u>hula</u> teacher, who submitted that geothermal development would be an invasion of Pele's domain, leading to a loss of belief, a loss of a sense of belonging to the land and the deity, and hence a loss of identity (P. Kanahele <u>In</u> BLNR, 1986a). Another expectation is that by tapping geothermal steam, wells would be drawing from Pele's substance, thereby depleting her vitality (Aluli <u>In</u> BLNR, 1986a).

The BLNR (1986b, 1986c) accepts that Pele is owed respect, but finds that respect for Pele does not bar geothermal development.

When the Pele practitioners asked the Hawaii Supreme Court to stop geothermal development on religious grounds, the Court turned down their petition. The Court found that the plaintiffs did not show that development would do significant harm to the exercise of their religion (Glauberman, 1988). The U.S. Supreme Court has refused to review the Hawaii decision.

More recently, about 40 Hawaiians have formed the Pele Defense Fund which carries out legal and public relations work (Hosek, 1988). The Pele Defense Fund has filed a challenge to a land exchange between the State and Campbell Estate and the subsequent creation of the Kilauea Middle East Rift Geothermal Subzone as infringing on "ceded lands" rights (Glauberman, 1988; Harada-Stone, 1988b). The Hawaii Supreme Court has denied certification to this challenge.

The point of contention between Pele practitioners and the State was, until 1988, whether respect for Pele ruled out geothermal development. The religious question has been succeeded by a broad opposition to technological development on the Big Island, not just to geothermal projects.

In newspaper advertisements appearing in early 1988, the Defense Fund presented 12 points in opposition to development. Pele was mentioned in only one of the 12 numbered paragraphs (Pele Defense Fund, 1988). According to the head of the company that created the advertisement, "the ad goes beyond the religious into the environmental" (Hosek, 1988).

5.0 Identity and Beliefs for Other Hawaiians

Attitudes towards Pele vary greatly:

- The Pele practitioners assert that Pele deserves great respect (Hosek, 1988);
- Some Hawaiians view themselves as traditionally connected to other gods or powers, and as little involved with Pele (Piianaia <u>In</u> BLNR, 1986a);
- Many Hawaii residents view respect for Pele as appropriate and prudent, especially on the Big Island (Thompson, 1987, Hartwell, 1987) -- yet they may support geothermal development and other projects the Pele practitioners oppose; and
- For some Christians, respect for Pele violates the First Commandment (Thompson, 1987). Kapi'olani's defiance of Pele in 1824 has long been seen as one of the heroic moments of Hawaiian religious activity (Bingham, 1848), and is still celebrated in hula (Hartwell, 1987).

The vast majority of Hawaiian survey respondents are interested in making a living in the existing economy, and report little interest in Hawaiian religion (Office of Hawaiian Affairs, 1986).

When Hawaiian respondents were asked about their attitudes towards the program to send geothermal energy to Oahu by an undersea cable, 67.4 percent favored the program, and only 19.7 percent viewed it unfavorably (SMS Research, 1987).

The issue of respect for Pele may be of concern to many Hawaiians who do not practice Hawaiian religion or oppose all geothermal development. Respect for Pele may be seen as respect for the Hawaiian people and for an aspect of Hawaiian tradition.

Prominent members of the Pele practitioners have spoken out for Hawaiian rights and groups on several islands of Hawaii (Uprichard, 1988). Also, groups opposed to geothermal development have claim to be protecting the land -- for example, the Citizens for Responsible Energy Development with Aloha 'Aina. In so doing, they link themselves with Hawaiian political groups, which have expressed deep reverence and concern for the land (Linnekin, 1983, 1985; Kirkpatrick, 1987).

Debates over geothermal development hence involve more than technical questions, and can touch on matters that are sensitive for some Hawaiian persons and groups. Disagreements and dissension among Hawaiians are a likely consequence of debates over development in Hawaii, but not of any specific project in particular. This impact may be limited in strength and duration, due to mechanisms in Hawaii's culture to overcome interpersonal divisions (Shook, 1985).

6.0 Summary of Anticipated Impacts

Hawaiians in Puna anticipate clear-cut local impacts of geothermal development. They are concerned with changes in their economy, and with access to land resources. They are also concerned with the general character of their region, as are other Puna residents.

Many Hawaiians elsewhere are concerned with the State's responsibilities and attitudes towards Hawaiians as a group -- geothermal development is only one of several topics where the State's commitment to Hawaiian citizens can be measured. They do not anticipate particular impacts so much as they look for a general policy of respect towards Hawaiians.

The Pele practitioners anticipate grave impacts of geothermal development on their god and on themselves. There is no evidence that many support their contention that Pele's well-being and Hawaiian identity are endangered by geothermal development.

7.0 Possible Responses and Mitigations

The State and geothermal developers can respond to some of the concerns of Hawaiians in Puna in several ways:

- Job training programs and programs to encourage the hiring of locally available labor can make employment available to Puna Hawaiians, among others;

- Archaeological surveys and recording, done before drilling and construction, can insure that disruption of traditional sites will be minimized;

- Botanical inventories of the geothermal subzones, including areas not slated for development, can be conducted before major construction activities begin, in order to identify medicinal and other traditional resources and to assure that supplies of such resources remain outside the areas where geothermal operations are planned; and

- If Puna residents are granted access to subzone land not in use for geothermal operations, such operations can be compatible with the gathering of traditional foods and medicines.

The disposition of revenues tied to public lands is an administrative and legal question outside the scope of this assessment. Similarly, the resolution of the Pele advocates' legal claims is a judicial matter.

In the present context, it can be noted that respect for Hawaiian tradition and for Hawaiians can be demonstrated by the State and by geothermal operators through consultation with Hawaiians on the Big Island and encouragement of Hawaiians to participate in community dialogues aimed at reducing negative impacts of geothermal development for Puna residents.

PART IX: PLANS, POLICIES, AND PERMITS

A. STATE PLANS AND POLICIES

1.0 Hawaii State Plan

Development of geothermal resources implements the Hawaii State Plan's objectives, policies and priority guidelines for energy use and development, and is consistent with other objectives, policies and priority guidelines contained in the Hawaii State Plan Revised adopted by the Hawaii State Legislature in May, 1986 (Chapter 226, HRS).

The two energy objectives of the State are increased energy self-sufficiency and dependable, efficient, and economical statewide energy systems capable of supporting the needs of the people. To achieve these objectives, the following policies have been adopted (Section 226-18, HRS):

- o Support research and development as well as promote the use of renewable energy sources.
- o Ensure a sufficient supply of energy to enable power systems to support the demands of growth.
- o Promote prudent use of power and fuel supplies through education, conservation, and energy-efficient practices.
- o Ensure that the development or expansion of power systems and sources adequately consider environmental, public health and safety concerns, and resource limitations.

The priority guidelines for energy use and development include, among others, encouraging "the development, demonstration, and commercialization of renewable energy resources." (Section 226-103 (f), HRS).

Development of geothermal resources also implements objectives and policies in the Plan that relate to achieving economic growth through the development and expansion of potential growth activities that serve to increase and diversify Hawaii's economic base. Two policies that are directly relevant are (Section 226-110, HRS):

- o Facilitate investment and employment in economic activities that have the potential for growth such as energy ....

- o Accelerate research and development of new energy-related industries based on .... underground resources .....

2.0 State Energy Functional Plan

Twelve "functional plans" have been prepared by State agencies in accordance with Chapter 226, HRS and adopted by the State Legislature. The purpose of the plans is to further define and implement the State Plan's comprehensive goals, objectives, policies and priority guidelines.

The State Energy Functional Plan developed by the Department of Planning and Economic Development (DPED 1984a) identifies alternate energy resource development as one of five areas of concern. The alternate energy resource development objective (Objective B) is to:

> Accelerate the transition to an indigenous renewable energy economy by facilitating private sector activities to explore supply options and achieve local commercialization and application of appropriate alternate energy technologies.

The Functional Plan states:

> Hawaii's near-total dependence on imported petroleum, spiraling oil prices, the net outflow of dollars for oil payments, and the political unrest of major oil-producing nations threaten local economic stability and the ability to serve energy needs over time. Support and assistance for private sector activities to develop local energy resources will reduce dependence on the world oil market, improve the State's balance of payments, and thus promote economic development, and increase the number and diversity of employment opportunities.

There are five implementing actions that directly relate to geothermal energy resource development:

- o Support continued implementation of the State Geothermal Commercialization Program to address and mitigate legal and institutional concerns. [B(1)(g)]

- o Designate, as appropriate, geothermal resource subzones within each of the land use districts to be used for the exploration, development, production and distribution of electrical energy from geothermal sources. [B(1)(A)]

- o Continue statewide alternate energy resource assessment studies, as appropriate, to supplement private sector investigations. High priority is given to the completion of resource assessments for geothermal energy on the islands of Hawaii and Maui. [B(2)(a)]

- o Continue geothermal research activities, as appropriate, to support commercialization efforts. [B(2)(g)]

- o Develop and demonstrate interisland electrical transmission technology. [B(2)(h)]

3.0 Geothermal Resource Subzones

In 1983, the State Legislature passed the Geothermal Resource Subzone Act (Act 296, SLH 1983), which amended Hawaii's Land Use Law (Chapter 205, HRS). The act authorized the designation of geothermal resource subzones in which geothermal exploration and development could occur (Section 205.5.1, HRS). The Act directs the Board of Land and Natural Resources (BLNR) to establish the subzones. The designated subzones are areas of significant geothermal potential where the BLNR has determined that the positive economic and social benefits of the development outweigh the potential negative environmental and social impacts.

The three areas within the Kilauea East Rift Zone considered as potential sources of geothermal power for this review -- Kapoho Section of the Lower East Rift Zone, Kamaili Section of the Lower East Rift Zone, and Kilauea Middle East Rift Zone-- have all been designated as geothermal resource subzones by the BLNR (DPED, 1986a). The potential actions discussed are therefore consistent with Hawaii's Land Use Law.

B. HAWAII COUNTY PLANS AND POLICIES

The Hawaii County General Plan, adopted in 1971, provides policy guidance for land development and other activities for the County of Hawaii. In February 1980, the Plan was amended to give special emphasis on energy self-sufficiency because of the heavy dependence on imported fuel and the escalating cost of electricity. The Plan is presently in the process of being revised and updated. Policies and courses of action described below are from the 1987 Draft Plan.

The County General Plan contains several policies supporting the development of alternate energy resources. Development of geothermal resources is consistent with these goals and policies. Energy goals for Hawaii County are to:

- o Strive towards energy self-sufficiency for Hawaii County.

- o Establish the Big Island as a demonstration community for the development and use of natural energy resources.

Policies relating directly to geothermal energy resource development are:

- o The County shall encourage the development of alternative energy resources.
- o The County shall encourage the expansion of energy research industry.
- o The County shall ensure a proper balance between the development of alternate energy resources and the preservation of environmental fitness.
- o The County shall strive to ensure a sufficient supply of energy to support present and future demand.

C. APPLICABLE PERMITS AND APPROVALS

1.0 Geothermal Resource Permits

Development of geothermal resources in a geothermal resource subzone within a Conservation District is under the jurisdiction of the State Board of Land and Natural Resources. The issuing authority for geothermal development in geothermal resource subzones located within Agricultural, Rural and State Land Use Districts on the island of Hawaii is the County of Hawaii Planning Commission.

Authority to determine whether proposed geothermal development activities should be allowed is conferred on the Planning Commission by Section 205-51, HRS, as amended, and outlined in Rule 12 of the Planning Commission's Rules of Practice and Procedure. The criteria for issuance of a permit are set forth in Section 12-6 as follows:

> The Planning Commission shall grant a geothermal resource permit if it finds that the applicant has demonstrated that:
>
> (a) The proposed geothermal development activities would not have unreasonable adverse health, environmental, or socioeconomic effects on residents or surrounding property; and
>
> (b) The proposed geothermal development activities would not unreasonably burden public agencies to provide roads and streets, sewers, water, drainage, school improvements, and police and fire protection; and

(c) There are reasonable measures available to mitigate the unreasonable adverse effects or burdens referred to above.

2.0 Comprehensive Permit System

The 1988 State Legislature established a comprehensive permit system for geothermal and cable system development (Act 301, Session Laws of Hawaii). The purpose of the act is described in the conference committee report on the proposed legislation as follows:

One of the major and fundamental difficulties in the development of geothermal resources on the island of Hawaii and the concurrent development of the cable system project that would move the generated electricity to the island of Oahu is the diverse array of federal state, and county land use, planning, environmental, and other related laws and regulations. This bill seeks to facilitate that permit process and thereby make the development of one of Hawaii's most significant energy sources more attractive to private developers.

In the section of the act stating the Legislature's findings and declaration of purpose, it is noted that the development of geothermal resources and a cable system would represent the largest and most complex development ever undertaken in the State and, because of the complexities of both projects, there is a need to provide firm assurances before companies will commit the substantial amounts of funds, time, and effort necessary to undertake these developments while at the same time ensuring the fulfillment of fundamental state and county land use and planning policies.

Act 301 designates DLNR as the lead agency for establishing a consolidated permit application and review process. The process is to include developing a list of all permits required for the project; forming an interagency group; identifying the role and functions of DLNR and the interagency group; identifying all permit review and approval deadlines; and establishing a schedule for meetings and actions of the interagency group.

In addition, DLNR is to establish a mechanism to resolve any conflicts that may arise between or among the department and any other agencies, including any federal agencies, as a result of conflicting permit, approval, or other requirements, procedures, or agency perspectives.

Act 301 requires DLNR to perform all of the permitting functions for which it is currently responsible and transfers to DLNR functions of the Land Use Commission related to district boundary amendments as set forth in Section 205-3.1 et seq., HRS and changes in zoning as set forth in Section 205-5, HRS. The Act also transfers the permit approval and enforcement functions of the Department of Transportation related to permits or approvals issued for the use of or commercial activities in or affecting the ocean waters and shores of the state under Chapter 266, HRS. By the transfer of these functions to DLNR, Act 301 does not overrule, alter, or change any existing permits.

Act 301 designates DLNR as the lead agency to coordinate and consolidate all required permit reviews by other agencies, and to the fullest extent possible by all federal agencies, having jurisdiction over any aspect of the project.

The procedure to be followed is outlined in the Act is as follows:

DLNR will develop a consolidated permit application form to be used for the proposed project for all permitting purposes.

The application will include whatever data about the proposed project that the department deems necessary.

Upon receipt of the consolidated permit application, DLNR will notify all agencies that it determines may have jurisdiction over any aspect of the proposed project as set forth in the application, and invite the federal agencies so notified to participate in the consolidated permit application process. State and County agencies so notified are required thereafter to participate in the consolidated permit application and review process.

Act 301 requires the representatives of DLNR and the state, county, and federal agencies to develop and sign a joint agreement among themselves which shall:

Establish and identify the members of the consolidated permit application and review team;

Identify all permits required for the project;

Specify the regulatory and review responsibilities of the department and each state, county, and federal agency and set forth the responsibilities of the applicant;

Establish a timetable for regulatory review, the conduct of necessary hearings, the preparation of an environmental impact statement if necessary, and other actions required to minimize duplication and to coordinate and consolidate the activities of the applicant, the department, and the state, county, and federal agencies; and

Provide that a hearing required for a permit shall be held on the island where the proposed activity shall occur.

The Department and each agency will issue its own permit or approval based upon its own jurisdiction. The consolidated permit application and review process will not affect or invalidate the jurisdiction or authority of any agency under existing law. The applicant will apply directly to each federal agency that does not participate in the consolidated permit application and review process.

Once the processing of the consolidated permit application has been completed and the permits requested have been issued to the applicant, the Department shall monitor the applicant's work undertaken pursuant to the permits to ensure the applicant's compliance with the terms and conditions of the permits.

Where the contested case provisions under chapter 91 apply to any one or more of the permits to be issued by the agency for the purposes of the project, the agency may, if there is a contested case involving any of the permits, be required to conduct only one contested case hearing on the permit or permits within its jurisdiction. Any appeal from a decision made by the agency pursuant to a public hearing or hearings required in connection with a permit will be made directly on the record to the Supreme Court for final decision subject to Chapter 602, HRS.

The Interagency Group established by Act 301 held its first meeting in September, 1988. The group is working with DLNR to establish a permitting and coordinating center and to develop administrative rules to implement the Act. Action on both of these items is expected to occur in mid-1989.

The permits and approvals required for the development of geothermal resources are listed in Table 9.1. Permits are needed from the Hawaii Departments of Health, Land and Natural Resources, and Labor and Industrial Relations, and from the County. The table does not include additional permits that might be required for the underwater cable.

TABLE 9.1

APPLICABLE REVIEWS, PERMITS, AND/OR APPROVALS

AGENCY AND PERMIT	LEGISLATION OR REGULATION	CONCERN
<u>State Permits</u>		
<u>Department of Health (DOH)</u>		
Underground Injection Control Permit: Approval to Construct; Approval to Operate	40 CFR 122 and 156, Regulations and Technical Criteria and Standards; Chapter 340E, HRS; DOH Administrative Rules, Title 11, Chapter 23	Groundwater protection
Air Pollution Control Permit: Authority to Construct or Modify a Facility; Permit to Operate	Clean Air Act (42 USC 1857h-7 et seq.) Chapter 342, HRS; DOH Adminstrative Rules, Title 11, Chapters 59 and 60	Air quality, odor control, public health
<u>Office of Environmental Quality Control</u>		
Environmental Impact Statement	Chapter 343, HRS DOH Adminstrative Rules, Title 11, Chapter 200	Environmental protection
<u>Department of Land & Natural Resources (DLNR)</u>		
Conservation District Use Permit	Chapter 183, HRS DLNR Adminstrative Rules, Title 13, Chapter 2	Required for commercial use of land within a Conservation District

TABLE 9.1 (Continued)

AGENCY AND PERMIT	LEGISLATION OR REGULATION	CONCERN
State Permits (Cont'd)		
Geothermal Exploration Permit	Chapters 177, 178, and 182, HRS DLNR Adminstrative Rules, Title 13, Chapter 183, Subchapter 2	Prevent waste; conserve resource; environmental protection; safety
Geothermal Well Drilling Permit	Chapters 177, 178, and 182. HRS DLNR Administrative Rules, Title 13, Chapter 183, Subchapter 8	Prevent waste; conserve resource; environmental protection; safety
Modification of Geothermal Well for Injection Use Permit	Chapters 177, 178 and 182. HRS DLNR Administrative Rules, Title 13, Chapter 183, Subchapters 8 and 9	Prevent waste; conserve resource; environmental protection; safety
Abandonment of Geothermal Well Permit	Chapters 177, 178, and 182 , HRS DLNR Administrative Rules, Title 13, Chapter 183, Subchapters 8 and 11	Prevent waste; conserve resource; environmental protection; safety
Geothermal Mining Lease	Chapter 182, HRS DLNR Administrative Rules, Title 13, Chapter 183	Protect leasee's investment; provide State revenue
Geothermal Plan of Operations	Chapters 177, 178, and 182, HRS DLNR Administrative Rules, Title 13, Chapter 183, Subchapter 7	Prevent waste; conserve resource; environmental protection; safety
Permit to Drill, Deepen, Redrill, Plug, or Alter a Water Well and to Install Replace, or Modify a Pump	Chapters 177 and 178, HRS DLNR Administrative Rules, Title 13, Chapter 166, Subchapter 8	Prevent waste; conserve resource

TABLE 9.1 (Continued)

AGENCY AND PERMIT	LEGISLATION OR REGULATION	CONCERN
State Permits (Cont'd)		
Department of Labor & Industrial Relations (DLIR)		
Pressure Vessel/Boiler	Chapter 397, HRS DLIR Administrative Rules, Title 12, Subtitle 8, Chapters 210, 220-224	Health and safety
Hawaii County Permits		
Geothermal Resource Permit	Chapter 205, HRS Hawaii County Planning Commission, Rule 12	Plant siting, aesthetics, noise guidelines. Required for land use in Urban, Rural or Agricultural Districts.
Grading, Grubbing, and Stockpiling Permit	Hawaii County Code, 1983, Chapter 10, Articles 2 and 3	Environmental impacts of earth moving activities
Building Permit	Hawaii County Code, 1983, Chapter 5 and Chapter 14, Article 9	Health and safety
Electrical Permit	Hawaii County Code, 1983, Chapter 9, Article 5, Division 1	Health and safety
Plumbing Permit	Hawaii County Code, 1983, Chapter 17, Article 2	Health and safety

PART X: LITERATURE CITED AND PERSONAL COMMUNICATIONS

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APPENDIX A: PUBLIC PARTICIPATION - GEOTHERMAL WORKSHOP

A geothermal workshop, sponsored by the Puna Community Council (PCC), to discuss the proposed 500 MW geothermal development and interisland cable system was held in Pahoa, Hawaii on November 9, 1988. The purpose of the meeting was: "to establish a continuing dialogue between the Puna community and the Department of Business and Economic Development (DBED) regarding geothermal development, issues, and concerns." The workshop had two goals:

1. To identify and define issues of concern to DBED and the Puna community regarding geothermal development, and

2. to prioritize two or three of these issues for continuing dialogue.

The meeting was facilitated by the Neighborhood Justice Center (Ms. Dee Dee Letts and Ms. Cathy Dashiell). According to the groundrules set prior to the workshop, only designated persons could take part in the dialogue. The following individuals participated:

o	Emmett Aluli	Pele Defense Fund
o	William Bonnet	Hawaiian Electric Company
o	Jerry Chang	State Representative
o	Mary Finley	PCC
o	Nelson Ho	PCC
o	Don Jacobs	PCC
o	Paul Jahlim	PCC
o	Allan Kawada	True/Mid-Pacific Geothermal Venture
o	Maurice Kaya	DBED
o	John Knox	Community Resources, Inc.
o	Russell Kokubun	Hawaii County Council
o	Dan Laine	PCC
o	Gerald O. Lesperance	DBED
o	Dee Dee Letts	Judiciary's Program on Alternative Conflict Resolution
o	Andrew Levin	State Senator
o	Diane Ley	PCC
o	Daniel Lum	DLNR
o	Stuart Marks	CREDAA
o	Marilynn C. Metz	MCM Planning

o	Dick Miner	PCC
o	Jim Morrow	American Lung Association Of Hawaii
o	James E. Moulds	PCC
o	Clyde Nagata	HELCO
o	Mary J. Owens	PCC
o	Milton Papineau	PCC
o	Ron Phillips	PCC
o	Bruce S. Plasch	Decision Analysts Hawaii, Inc.
o	Steve Radis	Dames & Moore
o	Maurice A. Richard	Ormat Energy Systems, Inc.
o	Jim Roberts	Pele Defense Fund
o	F. L. "Bud" Vuillemot	R. M. Towill Corporation
o	Ralph L. Yost	PCC

Non-participants who attended the meeting as interested individuals and/or resource persons included:

- o Bonnie Bazor
- o Andrea Gill Beck
- o Elsa K. Dedman
- o Barbara Hill
- o Paul Jaklkin
- o Randal Lee
- o Rod Moss
- o Ken Morikami
- o Albert Nakaji
- o Sus Ono
- o Ralph Patterson
- o Ginger Plasch
- o Dick Poirier
- o Oz Stender
- o Cynthia Thielen

The group raised issues, concerns and questions about geothermal development, transmission lines and the interisland cable. Copies of the complete "group memory" of the session were sent to the PCC and other participants in the workshop. A brief summary of <u>some</u> of the questions and comments raised at the workshop, relevant to this environmental review, follows:

o Planning Concerns

<u>Comments/questions.</u> The community would like a complete project plan: wells, lines, etc. A variety of questions need to be answered on who will construct, when, where, number of towers/lines, access, switching facilities, etc. There is a need for coordinated planning - projections for the future, including uses for power, such as spaceport, if off island transmission is not feasible. Are manganese

nodules processing and spaceport sufficient reasons for geothermal development on Big Island, if interisland cable doesn't work?

Infrastructure requirements such as roads, health and safety and emergency medical needs, have not been addressed. Improvements must be in place before development occurs. There may be trade-offs that could occur. Rate of the development of the resource in Hawaii county and how it proceeds needs to be discussed.

The PCC is concerned about high voltage transmission lines. They oppose building across residential lots; they are concerned about storm dangers with lines, visual intrusion, TV/etc. interference and lower property values. There is also concern over lack of planning of transmission line routes. PCC believes that there should be a single corridor in which all lines for the Big Island and other islands run.

Responses. There is definitely a desire to develop geothermal on the Big Island, probably a geothermal resource in the range of 500 MW, and to convey that resource to other islands. Specific development locations have not been identified as yet, however, DBED is responsible for appropriate planning. DBED will do a "concrete" program to address issues such as siting of plants and transmission line corridors. Presently they are limited by lack of funds, however, DBED intends to request additional funding from the 1989 Legislature. At present, the Department is looking at having a full time person within DBED assigned to geothermal. Questions concerning geothermal use for other industries would be addressed in an EIS for the development.

o Reliability

Comments/questions. What happens in the future if, because of volcanic activity, the existing geothermal lines and equipment must be removed? What if the 500 MW cable goes off line or is unusable after it has been working?

Responses. Reliability is a legitimate issue. Consequences of failure need to be addressed. Risks of power going "off-line" are there, but will be the same as with any generating plant. Reliability questions would have to be answered before HECO would proceed. The 500 MW system will be tested; there would also be a standby cable system. The State wants the "private sector", probably a consortium, to develop both the interisland cable and the geothermal resource at one time. The consortium would be responsible for delivering the energy to Oahu. HECO would buy the power. The consortium would be responsible for what would happen if lines, cables or other equipment malfunctions; the assumption is that malfunctioning or downed lines and/or equipment would be repaired.

- Costs and Benefits

<u>Comments/questions.</u> Is geothermal really a "foregone" conclusion? What criteria would be used in making a decision to proceed? If the interisland cable is not feasible, what are the alternatives?

<u>Responses.</u> Cost will be a factor in determining whether to proceed with the development. If geothermal can't be transported off island, then development will be scaled back. Research indicates that the cable is feasible, however, questions still exist concerning laying it interisland. This problem is currently being worked on.

<u>Comments/questions.</u> What would be the cost of the 500 MW development? Is 500 MW the most justifiable economically? Who picks up the tab if cost is higher than planned? Who is responsible if the program is turned over to private developers and then it fails?

<u>Responses.</u> Estimated costs are presented in a report by Decision Analysts Hawaii, Inc. We don't know as yet whether or not 500 MW is the most justifiable economically, however, any economic analysis has to look not just at cost, but also at amounts of electricity needed and can the technology produce enough in a reliable manner? DBED's contract would be negotiated so that the developer carries the cost. The responsibility for a successful private development remains with the utility companies.

<u>Comments/questions.</u> Geothermal must include and address local issues such as electrification. PCC emphasizes the need to tie in a solution to the Big Island's present electric problems with any development of geothermal. What benefits would the community receive from the development?

<u>Responses.</u> HELCO is looking to geothermal as a major source of energy for the Big Island. With other alternative energy suppliers, weather, and other conditions cause problems in continuous production of energy. Improvement of the existing road network and improved access are some examples of benefits to the

community that would be generated by the geothermal development.

<u>Comments/questions.</u> If 500 MW is sent to Oahu, what savings in fossil fuel imports into the state will occur? What percentage of total oil use will be eased?

<u>Responses.</u> Geothermal resources would replace six million barrels of oil per year. The savings in dollars would depend upon the price of oil - $35 bbl would equal savings of $250,000,000 year. It would replace approximately 16 percent of total oil used; this translates to 50 percent of its use for electrical generation on Oahu.

- Environmental Issues

<u>Comments/questions.</u> What is the environmental review report? What are the air quality findings in the report? Was the worst case studied? We need to take a much closer look at air quality problems.

<u>Responses.</u> The environmental review is intended to be an objective overview of existing data, questions, recommendations. Development of a scenarios concerning large scale geothermal in order to visualize a development of that magnitude, pull it together, point to future studies, provide some answers, and provide an opening for dialogue. Air quality was studied for normal operations. Normal operation of a plant would be at full operating level and not at worst case scenario. (Note: since this meeting an additional, "worst case", analysis was undertaken).

<u>Comments/questions.</u> Air quality studies only covered the Puna area; the study area should include all of the Big Island. Air quality problems should be looked at in light of Hawaii's unique geology. Was the eruption problem looked at? We need to look at air quality effects on Kona and Hilo - especially in conjunction with eruptions. Also, the acid rain problem needs study. What is the definition of BACT (Best Available Control Technology) for a vented well? Especially with the extra air problems because of volcanoes on the Big Island

<u>Responses.</u> Emissions from natural factors such as the volcano, are much higher than geothermal development emissions. Existing data from the Puna area was used in the computer models. These data showed high levels of H_2S during an eruption. The models showed that the increase contributed by geothermal operations was

insignificant. A malfunctioning well would have localized impact, hard to compare to volcano side-effects which are regional.

Comments/questions. Where is this development going to be? In light of conservation areas being natural and sensitive areas. What justification is being used for allowing geothermal wells in conservation areas?

Responses. Development of the geothermal resource needs to take place at the best heat/power source; this must be weighed against other factors, such as environmental impact. At the present time, we need more exploratory drilling in order to know where to develop.

Comments/questions. There is a need for evaluation of water quality, wildlife quality, and plant life quality. Nothing can compensate for environmental losses, environment must be addressed further and in detail. What is the "value" of a natural resource. Can you account for destroying it? Have to set independent value on protection of indigenous resources. What is the value of the natural biota in Hawaii? Money cannot be sole result/standard, environment must be considered

Environmental monitoring of plant operations should be undertaken by a independent agency/group, not by the party that owns/runs a geothermal development. Independent monitoring is a critical element to success. A California model (AB 3180) and the US Fish & Wildlife Service Habitat Evaluation Program (HEP), a potential system for evaluation of the environment, are incorporated into this appendix.

- Economic Impacts

Comments/questions. Where/how does Big Island/Puna district benefit from development of geothermal?

Responses. Even though the industry is heavily automated, approximately 200 jobs would be created by the development. In addition, there will be a $10 mil increase in property tax revenues to the County.

- Other Comments

Providing for community participation - real involvement - is critical. The cost of not having adequate community participation, such as delays due to contested permits, needs to be looked at. The community needs to see a commitment from DBED to look at and address the issues raised at the workshop.

- Next Issues for Discussion

  The group felt that the following issues were the most important for the next discussions regarding geothermal:

  - **Environmental.** Air quality standards, worst case scenarios, water quality standards, independent monitoring of a geothermal project.

  - **H.R. No. 109.** Where transmission lines will go;issues of small versus large and its impacts and compensation to those adversely impacted, if any.

  - **Master Project Plan For the Future.** Need for coordinated planning; economics; specific time line; routes; growth accommodation; uses for power, if any, if off island transmission is not feasible.

THE HABITAT EVALUATION PROCEDURES

INTRODUCTION

When the National Environmental Policy Act (NEPA) became law in 1970, it marked the beginning of a new "era" in terms of the way projects would be evaluated and, ultimately, planned. NEPA requires that an Environmental Impact Statement (EIS) be prepared so that the relative environmental costs and benefits of project alternatives can be considered in the decision making process along with economic values. A significant problem with this process, however, is that it is relatively easy to quantify economic values of a project, but extremely difficult to quantify environmental values.

In response to continued pressure to have a scientifically-based, defensible means of identifying impacts and determining mitigation requirements, the U.S. Fish and Wildlife Service (FWS) developed and, in 1976, published The Habitat Evaluation Procedures (HEP). HEP represents the efforts of FWS to develop a uniform system for describing an existing wildlife resource base, quantifying project impacts, and determining compensation for project-related losses. Since its publication, HEP has been refined substantially and is, today, the most comprehensive system available for quantifying fish and wildlife values.

OBJECTIVES

The primary objectives of HEP are as follows (modified from Schamberger and Farmer [1978]):

1. Provide a methodology to quantitatively assess baseline (existing) conditions in a given area for fish and wildlife in nonmonetary terms.

2. Provide a uniform system for predicting impacts on fish and wildlife resources.

3. Display and compare the beneficial and adverse impacts of project alternatives on fish and wildlife resources.

4. Provide a basis for recommending project alterations to compensate for or mitigate adverse effects on fish and wildlife resources.

5. Provide data to decision makers and the public from which sound resource and project decision can be made.

WHAT IS HEP?

HEP is based on the fundamental assumption that habitat quality and quantity can be numerically described. It is a species-habitat approach to impact assessment, and habitat quality for selected evaluation species is documented with an index, the Habitat Suitability Index (HSI). This value is derived from an evaluation of the ability of key habitat components to supply the life requisites of selected species of fish and wildlife. Evaluation involves using the same key habitat components to compare existing habitat conditions and optimum habitat conditions for the species of interest. Optimum conditions are those associated with the highest potential densities of the species within a defined area. The HSI value obtained from this comparison thus becomes an index to carrying capacity for that species.

The index ranges from 0.0 to 1.0, and for operational purposes in HEP, each increment of change must be identical to any other. For example, a change is HSI from 0.1 to 0.2 must represent the same magnitude of change as a change from 0.2 to 0.3, and so forth. Therefore, HSI must be linearly related to carrying capacity. This is an operational restriction imposed by the use of HSI in HEP. However, it is a restriction easily complied with; if the relationship between HSI and carrying capacity is unknown, it is assumed to be linear. If the relationship is nonlinear, it is converted to a linear function.

HEP attempts to incorporate concepts from both the population and habitat theories by evaluating habitat quality for specific species. Prior to the recent version of HEP, this was done subjectively based on the professional judgment of a team of biologists. The habitat quality values were multiplied by area and aggregated to obtain a "habitat" score. In the recent version of HEP, HSI values are obtained for individual species through use of documented habitat suitability models employing measurable key habitat variables (e.g., percent canopy closure). The HSI values are multiplied by area of available habitat to obtain Habitat Units (HU's) for individual species. These values are used in the HEP system for comparative purposes. No aggregation of species' HSI (or HU's) occurs.

Many potential users tend to consider the HSI value as synonymous with the entire HEP system. This is not the case. HEP can be compared to a bookkeeping ledger; both passively display, and thereby document, values obtained from other sources. HEP is a data management system; it is the data it manages, i.e., the index of quality and the quantity of available habitat, which are of interest in impact assessment.

Other aspects of HEP worth noting include the following:

1. HEP can be used to document differences in quality (HSI) and quantity (area) between existing habitat conditions (baseline) and various projected future sets of conditions. Future scenarios, for example, that could be evaluated with HEP might include (a) construction phase without mitigation; (b) construction phase with mitigation; (c) various specific points in time, such as 5, 10, 20, or 50 years into the future; or (d) project completion with and without mitigation.

2. Relative to mitigation, HEP can be used to determine such things as (a) the amount of mitigation necessary to compensate for project impacts; and (b) whether full compensation can be achieved in a given area.

3. A significant advantage of HEP is that it clearly documents the habitat values assigned and the process used to produce the impact and mitigation values.

In summary, HEP is a convenient means of documenting and displaying, in standard units, the predicted effects of proposed actions. It is a tool that can be used by planners and resource managers who must make knowledgeable decisions.

USES OF HEP

HEP an be used at various stages in project planning and evaluation. It is during the early stage of project planning that HEP can be especially effective through quantification of baseline habitat conditions and predictions of the relative costs and benefits of development alternatives and contemplated mitigation.

Once alternative project plans (including "no project") are formulated, HEP can be used to quantify and display (or compare) their relative ecological impacts. After the alternatives are assessed, conclusions can be made concerning the ecological acceptability or unacceptability of the various plans. Thus, HEP can be used for: (1) inventory of baseline habitat conditions; (2) formulating alternative plans; (3) alternative site evaluations; (4) alternative plan evaluations; and (5) determining compensation requirements.

SUMMARY

The U.S. Fish and Wildlife Service has spent much time and money since 1976 in an effort to fill a long-standing need: the ability, on a scientifically sound basis, to quantify otherwise abstract or qualitative fish and wildlife resource values for use in project planning and evaluation. The result has been the development and continued refinement of the Habitat Evaluation Procedures (HEP). Although not perfect, the methodology has generally been accepted by resource managers as a sound approach to fish and wildlife resource assessment. HEP, along with other ecological data, provides a solid format for evaluating project proposals and, ultimately, supporting or opposing specific plans on ecological grounds.

LITERATURE CITED

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Assembly Bill No. 3180

CHAPTER 1232

An act to add Section 21081.6 to the Public Resources Code, relating to environmental quality.

[Approved by Governor September 23, 1988. Filed with Secretary of State September 23, 1988.]

LEGISLATIVE COUNSEL'S DIGEST

AB 3180, Cortese. Environmental impact reports: mitigation findings.

(1) The California Environmental Quality Act prohibits a public agency from approving or carrying out a project for which an environmental impact report identifies significant environmental effects, unless one of specified findings relative to mitigation of those effects has been made. If no significant effect on the environment would occur, a negative declaration is required to be made, which would identify potentially significant effects that would be avoided or mitigated, as specified.

This bill would require the agency in making one of those findings, or adopting a negative declaration, to adopt a reporting and monitoring program for adopted or required changes to mitigate or avoid significant environmental effects. The bill would require an agency having jurisdiction over natural resources affected by a project, if requested by a lead or responsible agency, to submit a proposed reporting or monitoring program for changes required or incorporated into the project at its request. The bill would impose a state-mandated local program by imposing new duties on local agencies.

(2) The California Constitution requires the state to reimburse local agencies and school districts for certain costs mandated by the state. Statutory provisions establish procedures for making that reimbursement.

This bill would provide that no reimbursement is required by this act for a specified reason.

The people of the State of California do enact as follows:

SECTION 1. Section 21081.6 is added to the Public Resources Code, to read:

21081.6. When making the findings required by subdivision (a) of Section 21081 or when adopting a negative declaration pursuant to paragraph (2) of subdivision (c) of Section 21080, the public agency shall adopt a reporting or monitoring program for the changes to the project which it has adopted or made a condition of project approval in order to mitigate or avoid significant effects on the environment.

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The reporting or monitoring program shall be designed to ensure compliance during project implementation. For those changes which have been required or incorporated into the project at the request of an agency having jurisdiction by law over natural resources affected by the project, that agency shall, if so requested by the lead or responsible agency, prepare and submit a proposed reporting or monitoring program.

SEC. 2. No reimbursement is required by this act pursuant to Section 6 of Article XIII B of the California Constitution because the local agency or school district has the authority to levy service charges, fees, or assessments sufficient to pay for the program or level of service mandated by this act.

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CONCURRENCE IN SENATE AMENDMENTS

AB 3180 (Cortese) - As Amended: June 15, 1988

ASSEMBLY VOTE 42-31 (April 28, 1988) SENATE VOTE 23-1 (August 11, 1988)

Original Committee Reference: NAT. RES.

DIGEST

Current law requires that an environmental impact report (EIR) be prepared by the agency which is carrying out or approving a project which may have significant impacts on the environment. These agencies are required to adopt feasible alternatives or mitigation measures in carrying out or approving these projects. If the project has no significant impact on the environment or has been revised to avoid significant impacts, the agency may adopt a negative declaration.

As passed by the Assembly, this bill required that an agency adopt a reporting or monitoring program for any project mitigation at the time that an agency adopts either a negative declaration on a project which has been modified to mitigate significant environmental impacts, or findings on an EIR.

The Senate amendments require an agency with jurisdiction over natural resources affected by the project to prepare, at the request of the lead agency, a proposed reporting or monitoring program.

FISCAL EFFECT

Unknown costs to state and local agencies for monitoring public projects.

COMMENTS

1) "Local Government Implementation of Mitigation Requirements," a recent study by R. A. Johnston, surveyed California cities and counties to determine if monitoring of mitigation was occurring. The author concluded that monitoring frequently did not occur and that it was difficult to tell if required mitigation occurred or was successful. The purpose of this bill is to ensure that mitigation is monitored. The bill is worded to give the agency the latitude to monitor the mitigation directly or rely on reports from the project developer.

- continued -

2) The provisions of this bill are consistent with National Environmental Policy Act, the regulations of which require that "a monitoring and enforcement program shall be adopted and summarized where applicable for any mitigation."

Paul Thayer
445-9367
8/22/88:anatres

AB 3180
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APPENDIX B

DESCRIPTION OF A 12.5/25 MW POWER PLANT

APPENDIX B: DESCRIPTION OF A 12.5/25 MW POWER PLANT

The information in this appendix was compiled from Revised Environmental Impact Statement for the Kahauale'a Geothermal Project, (Towill, 1982a) and the Final Supplemental Environmental Impact Statement to the Revised Environmental Impact Statement for the Kahauale'a Geothermal Project, (True/Mid-Pacific Geothermal Venture, 1986).

1.0 Power Plant Design

Figure B-1 is a perspective drawing for a 12.5 MW power plant. The site plan (Figure B-2) indicates the general layout of the building, cooling tower, fence and parking area, together with space provisions for future expansion with an identical 12.5 MW for a total plant capacity of 25 MW.

The power plant building for a system capable of producing 12.5 MW would most likely be a two-story fully enclosed structure, approximately 90 feet by 40 feet by 50 feet high. Typical turbine generator building and equipment arrangements and elevations are shown in Figures B-3 and B-4. As shown in the aforementioned Figures, the ground floor slabs would be constructed at elevation of about three feet above normal grade and the main operating floor would be 22 feet above the ground floor.

The turbine generator would be located at the operating level. A concrete pedestal on rigid mat foundation would support the turbine generator and main condenser units. The pedestal would be of ample rigidity such that no resonance in the natural frequency of the pedestal foundation and the turbine-generator unit would occur.

Instrumentation equipment enclosures, switchgear room and associated electrical equipment, and enclosed personnel areas would be air conditioned and slightly pressurized to maintain a positive air flow of clean filtered air from the equipment and personnel areas to the exterior.

2.0 Gathering and Injection System

Figure B-5 illustrates a typical gathering and injection system for a 12.5 MW power plant showing the flow of geothermal fluids into and from the power plant. The hot mixed brine and steam flow would enter the high pressure flash drum and the portion flashed to steam would be directed to a single stage

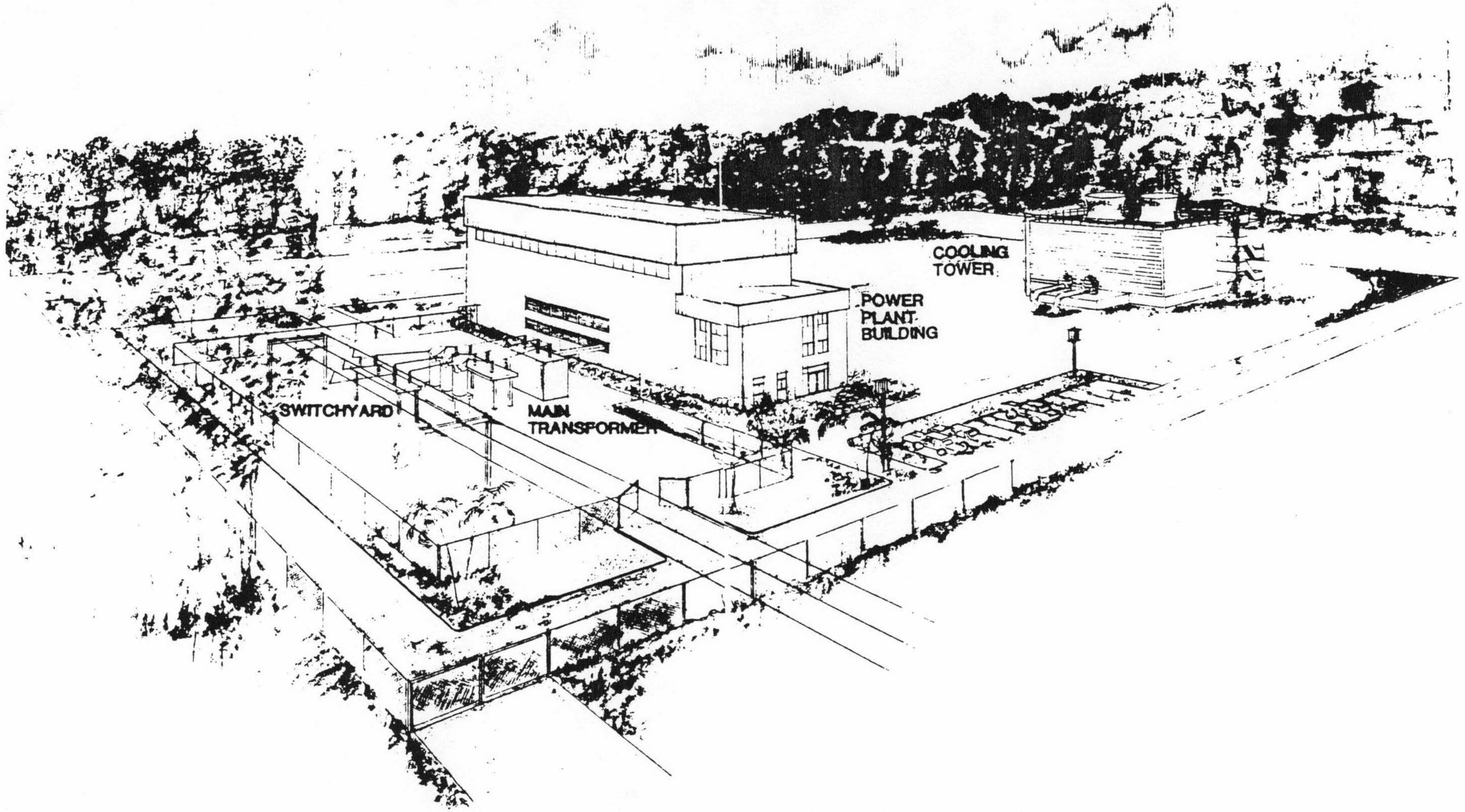
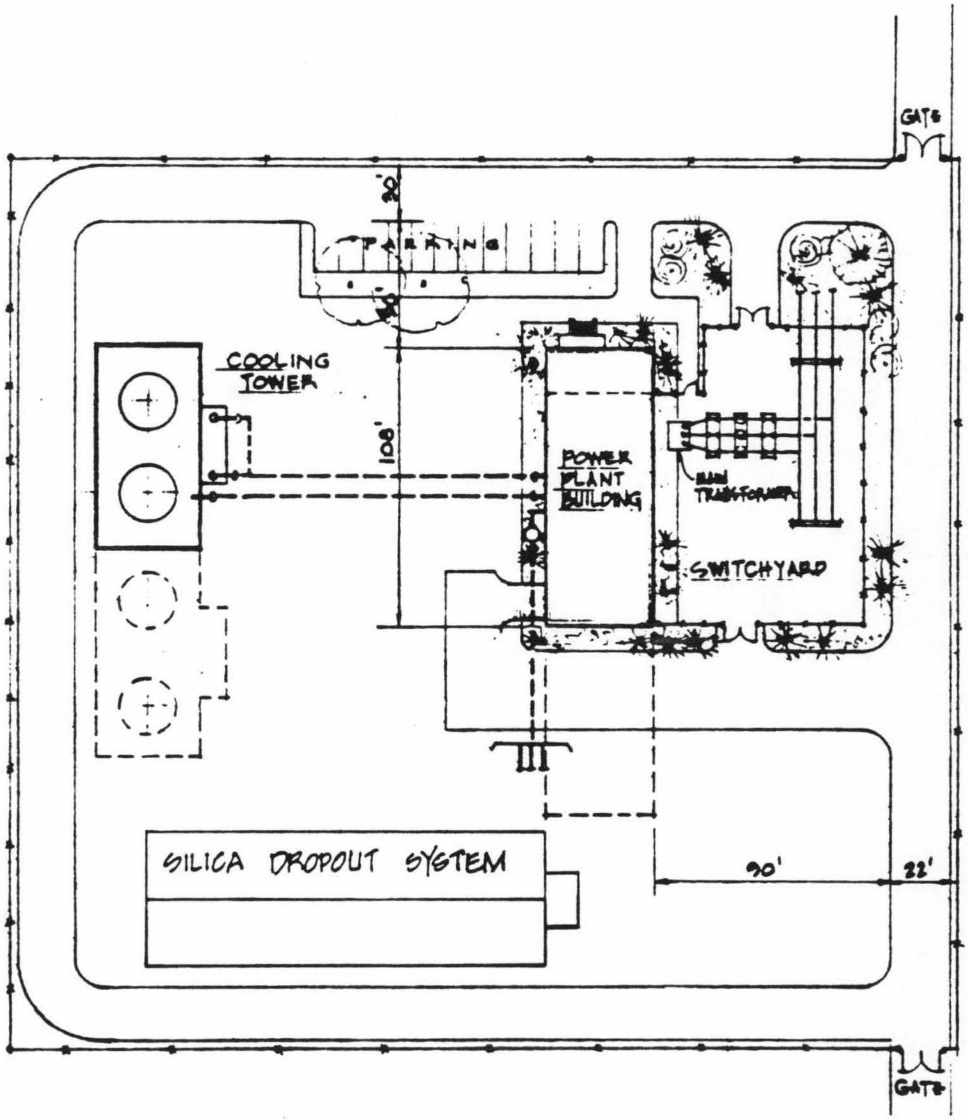


Figure B-1

12.5 MWe POWER PLANT: PERSPECTIVE

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.



100 0 100 200

SCALE IN FEET

Figure B-2
12.5 MWe POWER PLANT
(WITH EXPANSION TO 25 MWe): SITE PLAN

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

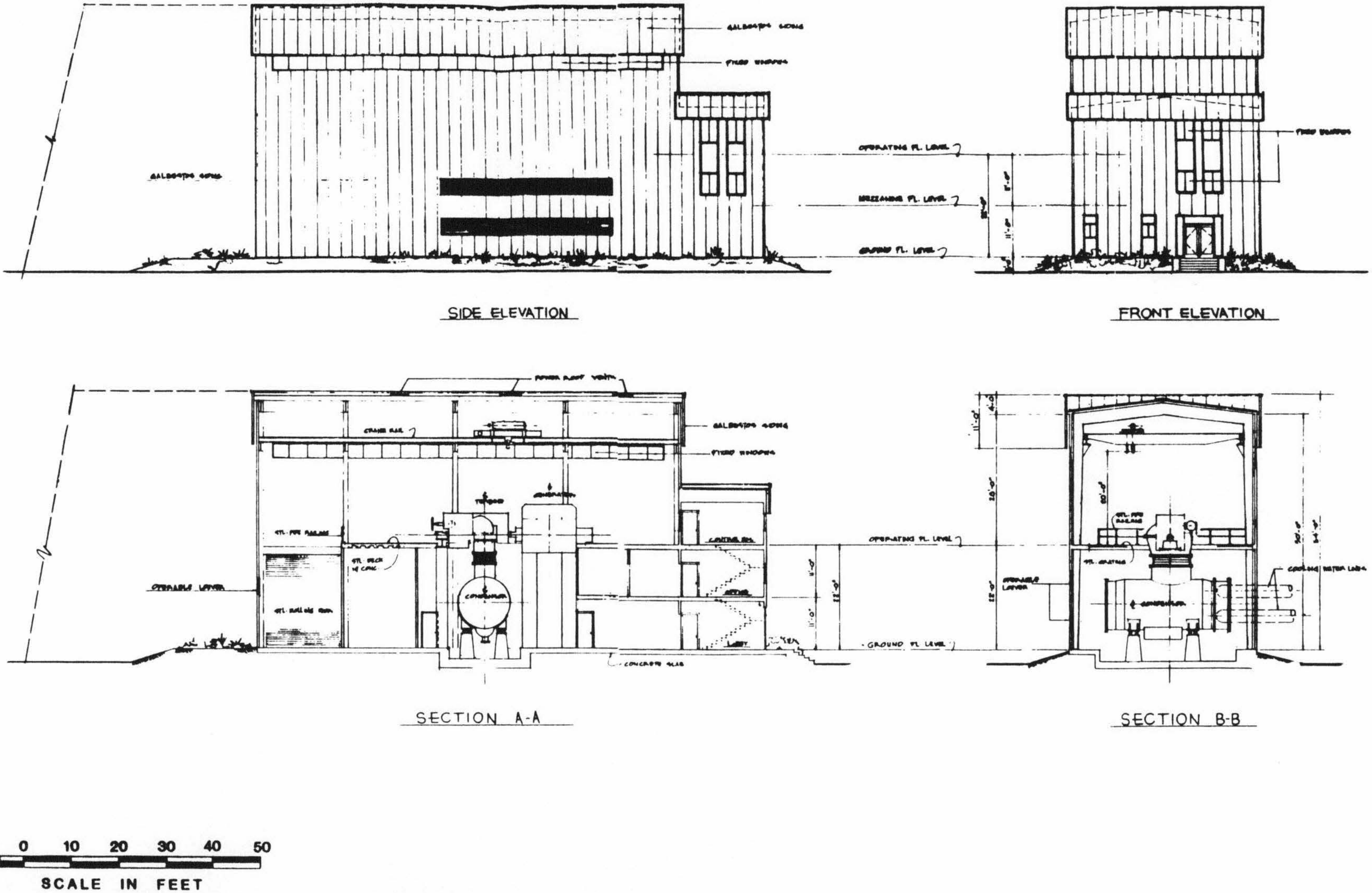
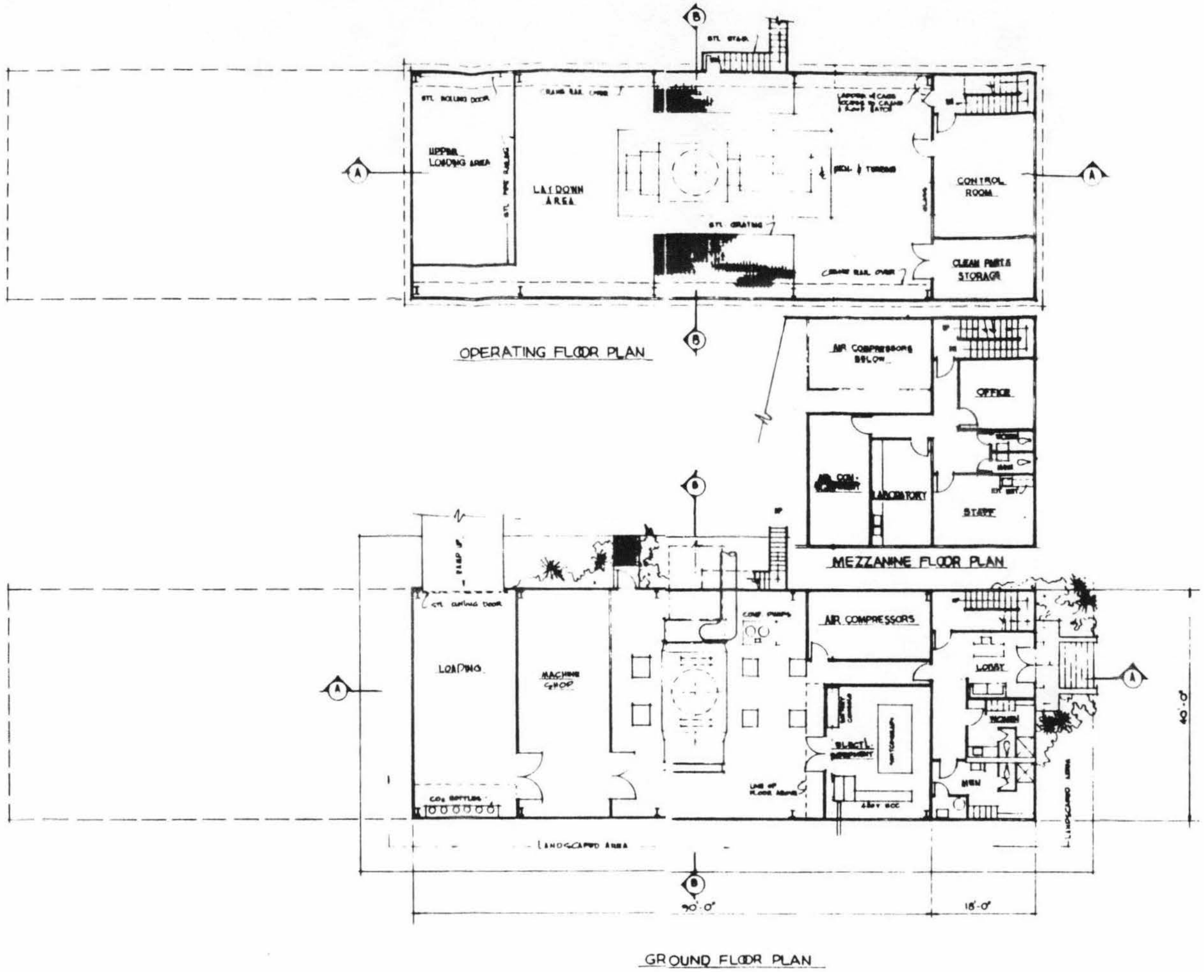


Figure B-3

12.5 MWe POWER PLANT: ELEVATIONS AND SECTIONS

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.



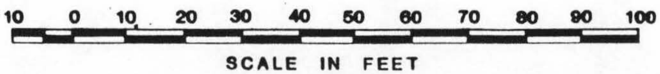


Figure B-4

12.5 MWe POWER PLANT: FLOOR PLANS

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

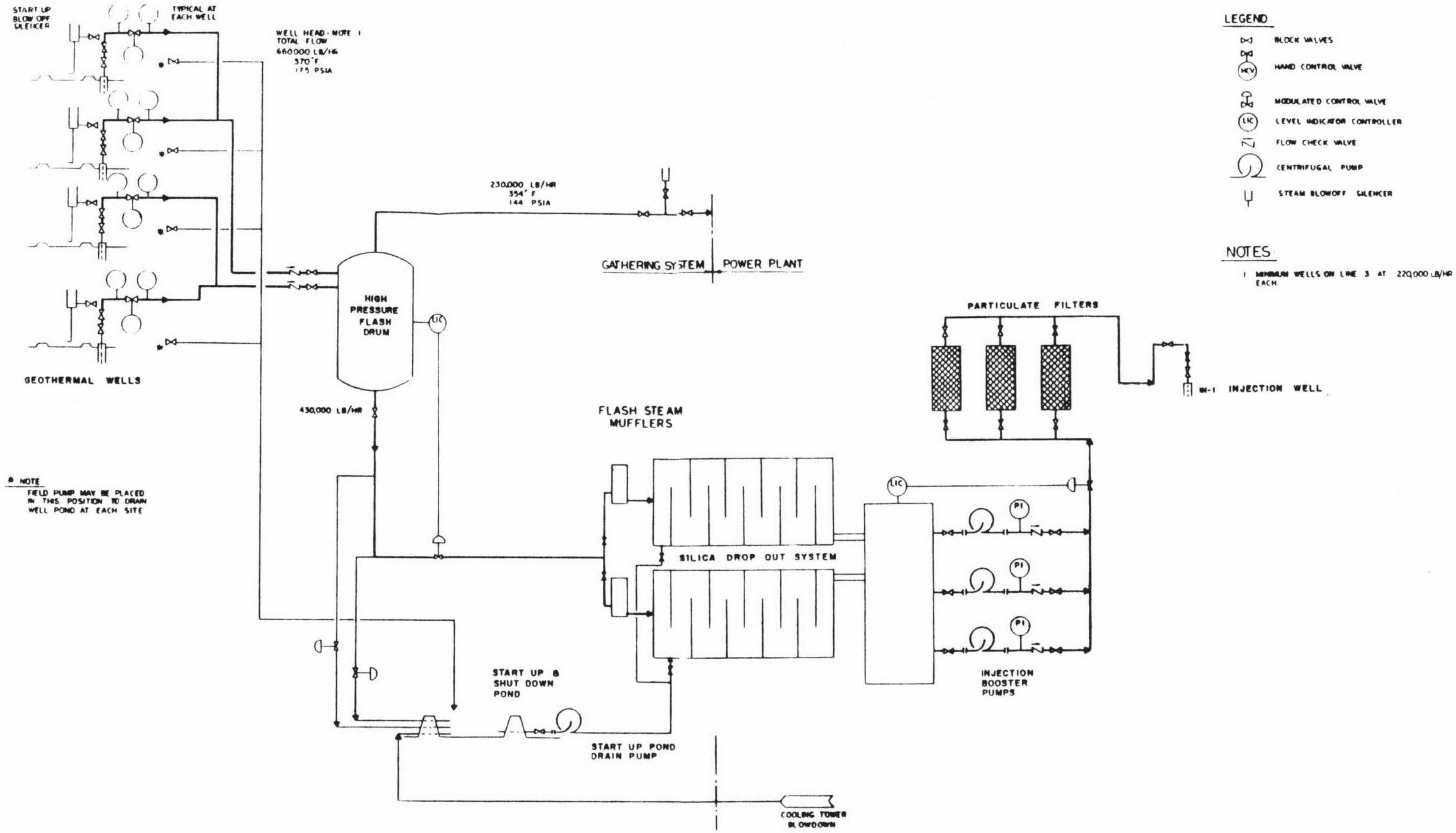


Figure B-5

12.5 MWe POWER PLANT: GATHERING AND INJECTION SYSTEM

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

turbine. The unflashed brine would then be directed to the flash steam mufflers, the silica dropout pond and to the suction header of the injection booster pumps.

3.0 Turbine Generator Systems

The 12.5 MW steam turbine would typically be a single pressure, single flow, impulse type condensing unit with a single cylinder, direct coupled to a totally enclosed air cooled generator. It would include a single pressure admission condensing unit. The equipment would include all the necessary automatic tripping devices required to protect the unit when a malfunction occurs.

The turbine blading would be stiff and short, with stress levels considerably lower than those supplied for comparable fossil fuel steam turbines and would utilize those features which would result in long-term reliable service with geothermal steam. Corrosion resistant materials would be specified for turbine internals in contact with geothermal steam.

The generator supplied with the turbine would be designed in accordance with the latest standards of American National Standards Institute C50.10-75, and C50.13-75 and applicable National Electrical Manufacturers Association and Institute of Electrical and Electronic Engineers, Inc., standards.

The condenser would be designed and constructed, where applicable, to conform with the latest American Society of Mechanical Engineers Code and would be of the surface type. The condenser would typically be constructed of carbon steel. Internal parts such as tubes and tube plates would be stainless steel. Water boxes would be carbon steel with epoxy coating. The liquid level in the condenser would be controlled by automatic liquid level controller. All the condensate from the geothermal steam would be returned to the cooling tower. Makeup water for the cooling water system would be provided from the steam condensate.

4.0 Auxiliary Systems and Internal Power Requirements

All necessary auxiliary systems would be supplied in addition to the major systems of the power plant, and would be designed specifically for the special conditions imposed by the utilization of geothermal steam and the site environment. The auxiliary systems include, but are not limited to the following:

- Auxiliary Cooling Water System
- Turbine Generator Lubricating Oil System
- Instrument Air System
- Fire Protection System
- Noncondensable Gas Removal System

5.0 Controls and Instrumentation

A main control panel in the control room would contain electrical and pneumatic controls for the various electrical and auxiliary process systems. In general, pneumatic systems would be used for level, pressure, flow and valve controls. Pneumatic transmitters in the field would provide inputs to the panel-mounted indicators, controllers and recorders. Resistance temperature detectors would provide electrical temperature signals from the field to solid state electronic temperature indicators and controls. Electric control would be used for the turbine generator, switchgear and motors. An annunciator would alert the operator to off normal conditions and indicate causes for turbine trip.

6.0 Electrical System

Electrical power generated at 13.8 KV would be transmitted to the transmission line through a main step-up transformer. The transformer would be connected to the line through a group operated disconnect switch which would be equipped with a high speed grounding switch. The grounding switch would be operated only in the event of transformer malfunction.

The 13.8 KV station bus would be connected by an air circuit breaker to the generator and the low voltage side of the main step-up transformer. This bus would also supply power to the auxiliary transformer and to the steam gathering and injection pump system through fused load break switches.

The auxiliary transformer would step down the voltage from the 13.8 KV bus to 480V in order to supply the 480V switchgear and a motor control center. The auxiliary transformer would be of the unit substation type with fans and a 55/65°C rise. Capacity has been derated due to high ambient temperatures.

7.0 Energy Conversion (Process Systems)

The following paragraphs provide elementary descriptions of the steam cycle, circulating water systems, steam condensate system and exhaust of noncondensable gases. Taps would be located on these piping systems in order to withdraw samples of steam, condensate, noncondensable gases and cooling water. A technical laboratory organization would be retained to take these samples and perform chemical analysis as required.

Steam from the gathering systems would be supplied to the plant steam line at the boundary. A steam line pressure relief system would be installed for emergency shutdown of the turbine generator. Steam would then be piped to the turbine, and in smaller quantities, to the turbine gland seals, first noncondensable gas ejector and second stage noncondensable gas ejector. Turbine steam would be exhausted at 4 in. Hg Abs. downward to the shell side of a surface condenser. Cooling water flow through the horizontal condenser tubes would typically be in a multi-pass arrangement.

Two full capacity transfer pumps (one spare) would usually be provided to pump the condensate from the main condenser hot well to the cooling tower basin.

Noncondensable gases would be drawn off by a second stage steam jet ejector discharging into an after-condenser from which they are pumped to the noncondensable gas abatement system. Condensate from the inter-condenser would flow by vacuum pressure differential to the main condenser. Figure B-6 presents a Flow and Control Diagram for a typical 12.5 MW plant.

Two 60 percent capacity main circulating water pumps would be provided to pump cooling water from the cooling tower forebay through the main condenser, inter-condenser, generator heat exchanger, lubricant oil cooler, air compressor cooling system, and back to the sprays in the cooling tower. These main circulating water pumps would operate when the turbine generator is operating. An auxiliary cooling water pump would be provided to supply cooling water to essential heat exchangers when the turbine generator is shutdown. Cooling tower blowdown is required and is based on concentrations of treated makeup water. The blowdown would be pumped into the brine disposal system. Alternatively, it could be possible to discharge into a drain or percolation pond for initial plant start-up.

Based on the assumption that this resource would be similar to that of HGP-A, the noncondensable gases could consist of 0.2 percent by weight of the total steam flow. This value was used in establishing the Flow Diagram and would be reevaluated once initial production from this area is achieved and actual chemistry is known. Abatement systems would be designed for the concentrations of noncondensable gases and the chemistry of the fluids found at each site.

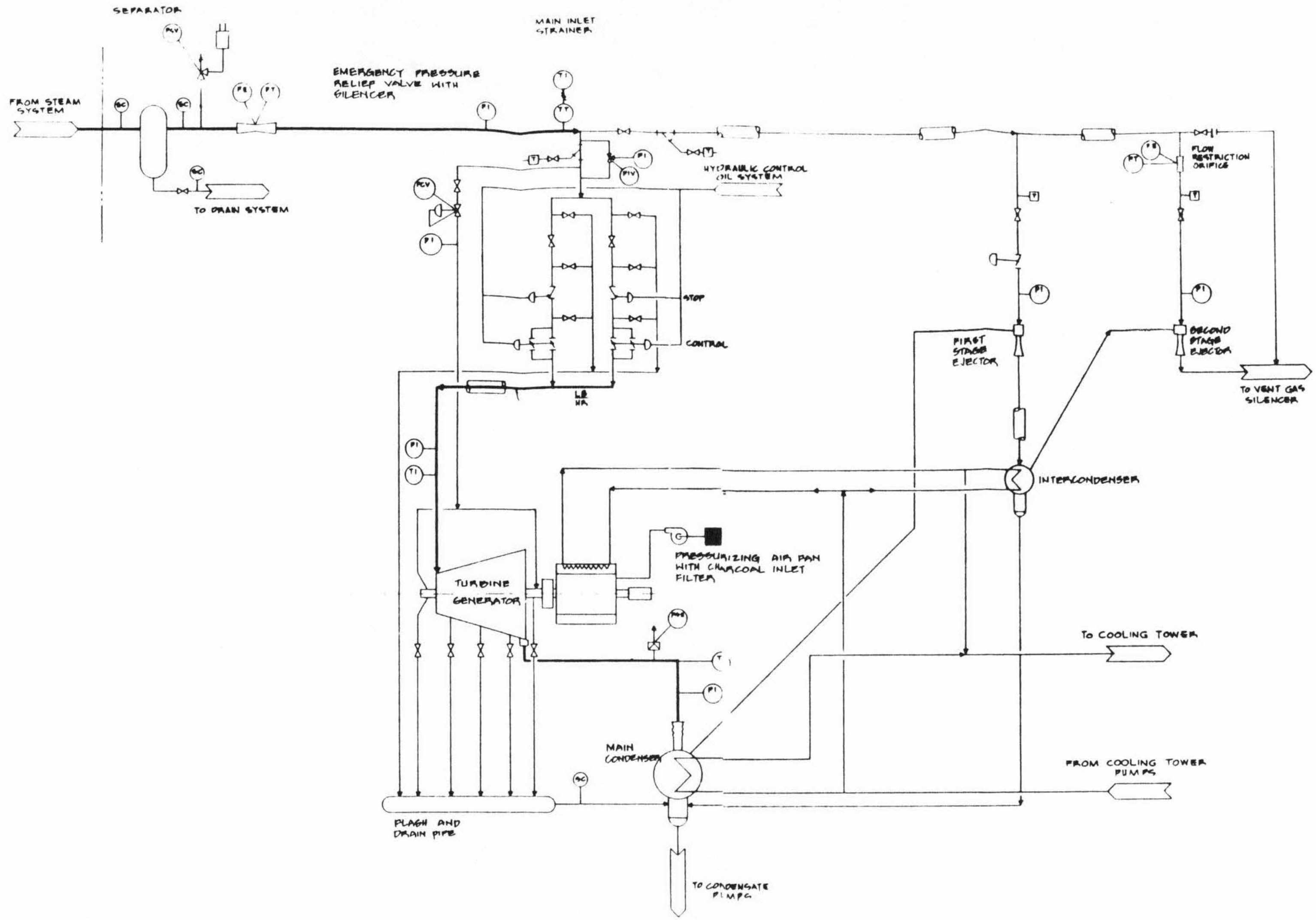


Figure B-6

12.5 MWe POWER PLANT: FLOW AND CONTROL DIAGRAM

SOURCE: ROGERS ENGINEERING CO., INC., SAN FRANCISCO, CALIFORNIA.

APPENDIX C

PLANT SPECIES LIST

APPENDIX C: PLANT SPECIES LIST

The plant species list is drawn primarily from Char and Lamoureux (1985a) and from later surveys of lands in the Middle East Rift Zone (Char and Lamoureux 1985b; Lamoureux, et al., 1988).

The plants are divided into four groups: Pteridophyta, Gymnospermae, Monocotyledonae, and Dicotyledonae. Within each group, families and species are arranged alphabetically. The taxonomy and nomenclature of the Pteridophyta (ferns and fern allies) follow Lamoureux's unpublished checklist of Hawaiian ferns (1984); taxonomy and nomenclature of the flowering plants (Monocotyledonae and Dicotyledonae) follow St. John (1973), except where more recently accepted names are used. Hawaiian names given in the checklist are in accordance with Porter (1972) or St. John (1973).

The plant list in Table C.1 provides the following information:

1. Botanical name with author citation.
2. Common English or Hawaiian name, when known.
3. Biogeographic status of each species.

The following symbols are used:

E	=	endemic = native only to the Hawaiian Islands
I	=	indigenous = native to the islands and also to one or more other geographic area(s)
P	=	Polynesian = Polynesian introduction, plants brought to the islands prior to Western contact (1778)
X	=	introduced or alien = brought to the islands by humans, accidentally or deliberately after Western contact.

Presence (+) or absence (-) of a particular species within each of six major vegetation types recognized in this study is indicated on the table. The numbers above each of the columns refers to the following vegetation types:

1	=	Lava
2	=	'Ohi'a-Uluhe woodland
3	=	'Ohi'a forest
4	=	Mixed lowland forest
5	=	Scrub
6	=	Agricultural lands

Table C.1 PLANT SPECIES CHECKLIST FOR PUNA GEOTHERMAL RESOURCE SUBZONES

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
<u>PTERIDOPHYTA</u>								
ADIANTACEAE								
Adiantum hisipidulum Sw.	Maiden-hair fern	X	-	-	+	-	-	-
Adiantum raddianum Presl	Maiden-hair fern	X	-	-	+	+	-	-
ASPIDIACEAE								
Dryopteris wallichiana (Spreng.) Hyl.	Lau-kahi	I	-	-	+	-	-	-
Tectaria crenata Cav.		X	-	-	-	+	-	-
ASPLENIACEAE								
Asplenium contiguum Kaulf.		E	-	-	+	-	-	-
Asplenium lobulatum Mett.	Pi’ipi’i-lau-manamana, ’anali’i	I	-	-	+	-	-	-
Asplenium nidus L.	’Ekaha	I	-	-	+	+	-	-
Asplenium polyodon Forst.		I	-	-	+	-	-	-
Asplenium unilaterale Lamk.	Pamoho	I	-	-	+	-	-	-
ATHYRIACEAE								
Athyriopsis japonica (Thunb.) Ching		X	-	-	+	-	-	-
Athyrium microphyllum (J. Sm.) Alston	’Akolea	E	-	-	+	-	-	-
Diplazium esculentum (Retz.) Sw.		X	-	-	-	-	-	+
Diplazium sandwichianum (Presl) Diels	Ho’i’o	E	-	-	+	-	-	-
BLECHNACEAE								
Blechnum occidentale L.	Blechnum fern	X	-	-	+	-	+	-
Sadleria cyatheoides Kaulf.	’Ama’u	E	+	+	+	+	-	-
Sadleria pallida Hook. & Arn.	’Ama’u	E	-	-	+	-	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
DENNSTAEDITIACEAE								
Microlepia strigosa (Thunb.)	Palai, palapalai	I	-	-	+	-	-	-
DICKSONIACEAE								
Cibotium chamissoi Kaulf.	Hapu'u-'i'i	E	-	-	+	+	-	-
Cibotium glaucum (J. Sm.) Hook. & Arn.	Hapu'u	E	-	+	+	+	-	-
Cibotium hawaiense Nakai & Ogura	Meu	E	-	-	+	-	-	-
ELAPHOGLOSSACEAE								
Elaphoglossum alatum Gaud. var. parvisquameum (Skottsb.) Ands. & Crosby	'Ekaha-ula, hoe-a-Maui	E	-	-	+	+	-	-
Elaphoglossum crassifolium (Gaud.) And. & Crosby	'Ekaha-ula, hoe-a-Maui	E	-	+	+	-	-	-
Elaphoglossum hirtum (Sw.) C. Chr. var. micans (Mett.) C. Chr.	'Ekaha-ula, hoe-a-Maui	E	-	-	+	-	-	-
Elaphoglossum pellucidum Gaud.	'Ekaha-ula, hoe-a-Maui	E	-	-	+	-	-	-
Elaphoglossum wawrae (Luerss.) C. Chr.	'Ekaha-ula, hoe-a-Maui	E	-	-	+	-	-	-
GLEICHENIACEAE								
Dicranopteris emarginata (Brack.) Rob.	Uluhe	E	+	+	+	+	+	-
Dicranopteris linearis (Burm.) Underw.	Uluhe	I	+	+	+	-	-	-
GRAMMITACEAE								
Adenophorus hymenophylloides (Kaulf.) Hook. & Grev.	Pai, palai-huna	E	-	-	+	-	-	-
Adenophorus periens L. E. Bishop	Palai-la'au	E	-	-	+	-	-	-
Adenophorus pinnatifidus Gaud.		E	-	-	+	-	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Adenophorus tamariscinus (Kaulf.) Hook. & Grev.	Wahine-noho-mauna	E	-	+	+	+	-	-
Adenophorus tripinnatifidus Gaud.		E	-	-	+	-	-	-
Grammitis hookeri (Brack.) Copel.	Maku'e-lau-li'i	E	-	-	+	-	-	-
Grammitis tenella Kaulf.	Kolokolo, mahina-lua	E	-	-	+	-	-	-
Xiphopteris saffordii (Maxon) Copel.	Kihi	E	-	-	+	-	-	-
HEMIONITIDACEAE								
Pityrogramma calomelanos (L.) Link	Gold fern, silver fern	X	+	+	-	-	+	-
HYMENOPHYLLACEAE								
Callistopteris baldwinii (Eaton) Copel.		E	-	-	+	-	-	-
Gonocormus minutus (Blume) v. d. Bosch		I	-	-	+	+	-	-
Mecodium recurvum (Gaud.) Copel.	'Ohi'a-ku	E	-	-	+	-	-	-
Sphaerocionium lanceolatum (Hook. & Arn.) Copel.	Palai-hinahina	E	-	-	+	-	-	-
Sphaerocionium obtusum (Hook. & Arn.) Copel.	Palai-lau-li'i	E	-	-	+	-	-	-
Vandenboschia cyrtotheca		E	-	-	+	-	-	-
(Gaud.) Copel.	Palai-hihi	E	-	-	+	+	-	-
LINDSAEACEAE								
Lindsaea ensifolia Sw. var. ensifolia		I	-	+	-	-	-	-
Sphenomeris chinensis (B.) Maxon	Pala'a, palapala'a	I	-	+	+	-	-	-
LYCOPODIACEAE								
Lycopodium cernuum L.	Wawae-'iole	I	-	+	+	+	+	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Lycopodium phyllanthum Hook. & Arn.	Wawae-'iole	E	+	+	+	-	-	-
Lycopodium polytrichoides Kaulf.	Wawae-'iole	E	-	-	+	-	-	-
Lycopodium venustulum Gaud.	Wawae-'iole	I	-	-	+	-	-	-
MARATTIACEAE								
Marattia douglasii (Presl) Baker	Pala, kapua'i hoki	E	-	-	+	-	-	-
NEPHROLEPIDACEAE								
Nephrolepis biserrata (Sw.) Schott	Fishtail sword fern	X	-	-	+	-	-	-
Nephrolepis cordifolia (L.) Presl	Ni'ani'au, kupukupu, 'okupukupu	I	-	-	+	-	-	-
Nephrolepis exaltata (L.) Schott	Ni'ani'au, kupukupu 'okupukupu	I	-	+	+	+	-	-
Nephrolepis multiflora (Roxb.) Jarrett ex Morton	Hairy sword fern	X	+	+	+	+	+	+
OPHIOGLOSSACEAE								
Ophioglossum pendulum L. ssp. falcatum (Presl) Clausen	Puapua-moe	E	-	-	+	+	-	-
POLYPODIACEAE								
Phlebodium aureum (L.) J. Sm.	Laua'e-haole	X	-	-	+	-	-	-
Phymatosorus scolopendria (Burm.) Pic.-Ser.	Laua'e, lauwa'e	X	+	+	+	+	-	-
Pleopeltis thunbergiana Kaulf.	'Ekaha-'akolea, pakahakaha	I	+	+	+	+	-	-
Polypodium pellucidum Kaulf.	'Ae, 'ae-lau-nui	E	+	-	-	-	-	-
PSILOTACEAE								
Psilotum complanatum Sw.	Moa, pipi	I	-	-	+	-	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Psilotum nudum (L.) Beauv.	Moa, pipi	I	+	+	+	+	-	-
Psilotum complanatum x nudum	Hybrid moa	I	-	-	+	-	-	-
PTERIDACEAE								
Pteris vittata L.		X	+	+	+	+	+	-
SELAGINELLACEAE								
Selaginella arbuscula (Kaulf.) Spring	Lepelepe-a-moa	E	-	-	+	-	-	-
THELYPTERIDACEAE								
Amauropelta globulifera (Brack.) Holtt.	Palapalai-a-Kama-pua'a	E	-	-	+	-	-	-
Christella cyatheoides (Kaulf.) Holtt.	Kikawaio	E	-	-	+	-	-	-
Christella dentata (Forsk.) Brownsey & Jermy	Downy woodfern	X	-	-	+	+	+	+
Christella parasitica (L.) Levl.	Woodfern, oakfern	X	-	-	+	-	-	-
Macrothelypteris torresiana (Gaud.) Ching		X	+	-	+	-	-	-
Pneumatopteris hudsoniana (Brack.) Holtt.	Lau-kahi	E	-	-	+	-	-	-
Pneumatopteris sandwicensis (Brack.) Holtt.		E	-	-	+	-	-	-
Pseudophegopteris keraudreniana (Gaud.) Holtt.	Waimaka-nui	E	-	-	+	-	-	-
VITTARIACEAE								
Vittaria elongata Sw.	Oheohe	I	-	-	+	+	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
GYMNOSPERMAE								
ARAUCARIACEAE								
Araucaria spp.	Cook pine, Norfolk Island pine	X	-	-	-	+	-	+
MONOCOTYLEDONAE								
ARACEAE								
Anthurium hybrids	Anthurium	X	-	-	+	-	-	+
Colocasia esculenta (L.) Schott.	Kalo, taro	P	-	-	-	+	-	+
Monstera deliciosa Liebm.	Monstera	X	-	-	-	+	-	-
Philodendron sp.	Philodendron	X	-	-	+	+	-	-
Scindapsus aureus (Lindl. ex Andre) Engl.	Taro vine	X	-	-	-	+	-	-
Syngonium auritum (L.) Schott.	Syngonium	X	-	-	-	+	-	-
CANNACEAE								
Canna indica L.	Canna	X	-	-	-	-	-	+
COMMELINACEAE								
Commelina diffusa Burm. f.	Honohono	X	-	-	+	+	+	+
CYPERACEAE								
Carex wahuensis C. A. Mey. var. rubiginosa F. W. Krauss		E	-	-	+	+	-	-
Cyperus haspan L.		X	-	-	+	-	+	-
Cyperus javanicus Houtt.	'Ahu'awa, 'ehu'awa	I	-	-	+	-	-	+
Cyperus rotundus L.	Nutsedge	X	-	-	-	-	-	+
Cyperus sp.		X	-	-	+	-	-	-
Fimbristylis dichotoma (L.) Vahl	Tall fringe rush	I	-	+	+	-	+	+
Fimbristylis pycnocephala Hillebr.		I	-	-	-	+	+	-
Kyllinga brevifolia Rottb.	Kili'o'opu, kyllinga	X	-	+	+	+	+	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Kyllinga nemoralis (J. R. & G. Forst.) Dandy ex Hutch. & Dalziel	Kili'o'opu, kyllinga	X	-	-	+	+	+	+
Machaerina angustifolia (Gaud.) Koyama	'Uki	I	+	+	+	+	+	-
Machaerina mariscoides (Gaud.) Kern ssp. meyenii (Kunth) Koyama	'Uki, 'aha-niu	I	+	+	+	+	+	-
Pycreus polystachyos (Rottb.) Beauv.		I	+	+	+	+	+	+
Rhynchospora lavarum Gaud.	Kuolohia, pu'uko'a	E	-	+	+	-	-	+
Rhynchospora sp.		X	-	-	+	-	-	-
Scleria testacea Nees	Scleria	E	-	-	-	+	+	-
Uncinia uncinata (L. f.) Kuek.		I	-	-	+	-	-	-
DIOSCOREACEAE								
Dioscorea bulbifera L.	Ho'i, pi'oi	P	-	-	-	+	-	-
Dioscorea pentaphylla L.	Pi'ia, pi'a	P	-	-	+	+	+	-
GRAMINEAE								
Andropogon glomeratus (Walt.) BSP.	Bush beardgrass	X	-	+	-	-	+	+
Andropogon virginicus L.	Broomsedge	X	+	+	+	+	+	+
Axonopus affinis Chase	Narrow-leaved carpetgrass	X	-	+	+	-	+	+
Axonopus compressus (Sw.) Beauv.	Broad-leaved carpetgrass	X	-	+	-	-	+	+
Bambusa spp.	Bamboo	X	-	-	-	+	+	+
Brachiaria mutica (Forsk.) Stapf.	Californiagrass	X	-	-	-	+	+	+
Brachiaria reptans (L.) Gard. & C. E. Hubb.		X	-	-	-	-	-	+
Chloris radiata (L.) Sw.	Radiate fingergrass	X	-	-	-	-	-	+
Chrysopogon aciculatus (Retz.) Trin.	Pilipili-'ula, goldenbeardgrass	X	-	-	-	+	-	-
Coix lachryma-jobi L.	Pu'ohe'ohe, Job's tears	X	-	-	-	+	+	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Cynodon dactylon (L.) Pers.	Manienie, Bermudagrass	X	-	+	-	-	-	+
Digitaria adscendens (HBK.) Henr.	Henry's crabgrass	X	-	-	-	-	-	+
Digitaria decumbens Stent	Pangolagrass	X	-	-	-	-	+	+
Digitaria eriantha Steud.		X	-	-	-	-	-	+
Digitaria fuscescens (Presl) Henr.	Creeping kukaepua'a	X	-	+	-	-	+	+
Digitaria radicosa (Presl) Miq.		X	-	+	-	+	-	-
Digitaria setigera Roth ex R. & S.		X	-	-	-	-	-	+
Digitaria timorensis (Kunth) Balansa		X	-	-	-	-	-	+
Eleusine indica (L.) Gaertn.	Goosegrass	X	-	-	-	-	+	+
Eragrostis sp.		X	-	-	-	-	+	+
Hyparrhenia rufa (Nees) Stapf	Thatchinggrass, jaragua	X	-	-	-	-	+	+
Isachne distichophylla Munro ex Hillebr.	Ohe	E	-	+	+	+	-	-
Melinis minutiflora Beauv.	Molassesgrass	X	-	+	-	+	+	+
Microlaena stipoides (Labill.) R. Br.	Pu'u lehua, meadow ricegrass	X	-	-	-	-	-	+
Oplismenus hirtellus (L.) Beauv.	Honohono-kukui, basketgrass	X	-	-	+	+	+	-
Panicum maximum Jacq. var. maximum	Guineagrass	X	-	-	-	-	+	+
Panicum repens L.	Wainakugrass	X	-	-	-	-	+	+
Paspalum conjugatum Berg.	Mau'u-Hilo, Hilo grass	X	-	+	+	+	+	+
Paspalum dilatatum Poir.	Dallisgrass, Australian watergrass	X	-	-	-	-	-	+
Paspalum orbiculare Forst. f.	Mau'u-laiki, ricegrass	X	-	+	+	+	-	+
Paspalum urvillei Steud.	Vaseygrass	X	-	+	+	+	+	+
Pennisetum purpureum Schumach.	Napiergrass, elephantgrass	X	-	-	-	+	+	+
Pennisetum setaceum (Forsk.) Chiov.	Fountaingrass	X	+	-	-	-	-	-
Poa annua L.	Annual bluegrass	X	-	-	-	-	-	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Rhynchelytrum repens (Willd.) C. E. Hubb.	Natal redtopgrass	X	-	+	-	-	+	+
Saccharum officinarum L.	Ko, sugarcane	P	-	-	-	-	+	+
Sacciolepis indica (L.) Chase	Glenwoodgrass	X	-	+	+	+	+	+
Schizostachyum glaucifolium (Rupr.) Munro	Ohe, Hawaiian bamboo	P	-	-	+	+	-	-
Setaria geniculata (Poir.) Beauv.	Perennial foxtailgrass	X	-	+	+	-	+	+
Setaria palmaefolia (Koen.) Stapf	Palmgrass	X	-	-	+	+	-	+
Sporobolus africanus (Poir.) Robyns & Tounay	African dropseed	X	-	+	-	-	+	+
Sporobolus diander (Retz.) Beauv.	Indian dropseed	X	-	-	-	-	-	+
Sporobolus indicus (L.) R. Br.	West Indian dropseed	X	-	-	-	-	+	-
IRIDACEAE								
Tritonia crocosmaeflora Nichols.	Montbretia	X	-	-	+	-	-	-
JOINVILLEACEAE								
Joinvillea ascendens Brong. & Gris.	'Ohe	E	-	-	+	-	-	-
JUNCACEAE								
Juncus effusus L.	Bog rush	X	-	+	+	-	-	-
Juncus planifolius R. Br.		X	-	+	+	-	-	-
Juncus tenuis Willd.		X	-	-	+	-	-	-
LILIACEAE								
Astelia menziesiana Sm.	Pa'iniu	E	-	-	+	-	-	-
Cordyline terminalis (L.) Kunth var. terminalis	Ki, ti	P	-	+	+	+	+	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Cordyline terminalis (L.) Kunth var. ferrea (L.) J. G. Baker	Red ti	X	-	-	-	-	-	+
Smilax sandwicensis Kunth	Hoi-kuahiwi	E	-	-	+	-	-	-
MUSACEAE								
Musa spp.	Mai'a, banana	P	-	-	+	+	-	+
ORCHIDACEAE								
Arundina bambusaefolia (Roxb.) Lindl.	Bamboo orchid	X	+	+	+	+	+	+
Phaius tankervilliae (Banks ex L'Her.) Bl.		X	-	+	+	-	-	-
Spathoglottis plicata Bl.	Philippine ground orchid	X	+	+	+	+	+	+
Vanda terres Lindl. x V. hookeriana Reichb. f.	Vanda	X	-	-	-	-	-	+
PALMAE								
Archontophoenix alexandrae (F. Muell.) H. Wendl. & Drude	Alexandra palm	X	-	-	-	+	+	-
Cocos nucifera L.	Niu, coconut palm	P	-	-	-	+	-	+
Pritchardia beccariana Rock	Lo'ulu	E	-	-	+	-	-	-
PANDANACEAE								
Freycinetia arborea Gaud.	'Ie'ie	E	-	-	+	+	-	-
Pandanus odoratissimus L. f.	Hala, pandanus	I	-	-	+	+	-	-
Pandanus sp.	Hala, pandanus	E	-	-	-	+	-	-
TACCACEAE								
Tacca leontopetaloides (L.) Ktze.	Pia	P	-	-	-	+	-	-
XYRIDACEAE								
Xyris complanata R. Br.		X	-	+	-	-	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
ZINGIBERACEAE								
Alpinia purpurata (Vieill.) K. Schum.	Red ginger, 'awapuhi-'ula'ula	X	-	-	-	-	+	+
Hedychium coronarium Koenig	'Awapuhi ke'oke'o, white ginger	X	-	-	-	+	-	-
Hedychium flavescens Carey	'Awapuhi melemele, yellow ginger	X	-	-	+	+	+	-
Zingiber zerumbet (L.) Roscoe	'Awapuhi kua hiwi	P	-	-	+	+	-	-
DICOTYLEDONAE								
ACANTHACEAE								
Nicoteba betonica (L.) Lindau	White shrimp plant	X	-	-	-	-	+	+
Odontonema strictum (Nees) Ktze.	Odontonema	X	-	-	-	-	+	+
Thunbergia fragrans Roxb.	White thunbergia	X	-	-	+	+	+	+
AMARANTHACEAE								
Alternanthera sessilis (L.) R. Br. ex R. & S.		X	-	-	-	-	-	+
Amaranthus spinosus L.	Spiny amaranth, pakai-kuku	X	-	-	-	-	+	+
Amaranthus viridis L.	Slender amaranth, pakai	X	-	-	-	-	-	+
ANACARDIACEAE								
Mangifera indica L.	Mango	X	-	+	+	+	+	+
Schinus terebinthifolius Raddi	Christmas berry	X	-	-	+	+	+	+
APOCYNACEAE								
Alyxia olivaeformis Gaud.	Maile	E	-	-	+	+	-	-
AQUIFOLIACEAE								
Ilex anomala Hook. & Arn.	Kawa'u	E	-	+	+	-	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
ARALIACEAE								
Brassaia actinophylla Endl.	Octopus tree, umbrella tree	X	-	-	-	+	-	-
Cheirodendron trigynum (Gaud.) Heller	Olapa	E	-	-	+	-	-	-
Tetraplasandra hawaiensis Gray var. hawaiensis	'Ohe	E	-	+	+	+	-	-
Tetraplasandra sp.	'Ohe	E	-	-	+	-	-	-
ASCLEPIADACEAE								
Asclepias curassavica L.	Butterfly weed	X	-	-	-	-	+	+
Gomphocarpus physocarpus E. Mey.	Balloon plant	X	-	-	+	-	-	-
BALSAMINACEAE								
Impatiens sultani Hook. f.	Impatiens	X	-	-	-	+	+	+
BEGONIACEAE								
Begonia sp.	Begonia	X	-	-	+	+	-	-
BIGNONIACEAE								
Spathodea campanulata Beauv.	African tuliptree	X	-	-	-	+	+	+
CAPRIFOLIACEAE								
Lonicera japonica Thunb.	Honeysuckle	X	-	-	+	-	-	+
CARICACEAE								
Carica papaya L.	Papaya, mikana	X	-	-	+	+	+	+
CARYOPHYLLACEAE								
Drymaria cordata (L.) Willd. ex R. & S.	Drymaria, pipili	X	-	-	+	-	+	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
CASUARINACEAE								
Casuarina cunninghamiana Miq.	River-oak casuarina	X	-	-	-	+	+	-
Casuarina equisetifolia Stickm.	Ironwood	X	+	-	-	+	+	-
Casuarina littoralis Salisb.	Black she-oak casuarina	X	-	-	-	+	-	-
CELASTRACEAE								
Perrottetia sandwicensis Gray	Olomea	E	-	-	+	-	-	-
COMPOSITAE								
Adenostemma lavenia (L.) Ktze.	Kamanamana	I	-	-	+	+	-	-
Ageratum conyzoides L.	Ageratum, maile-hohono	X	-	+	+	-	+	+
Ageratum houstonianum Mill.	Ageratum	X	-	-	+	-	+	+
Bidens pilosa L. var. pilosa	Spanish needle	X	-	-	-	-	+	+
Bidens pilosa L. var. minor (Bl.) Sherff		X	-	-	-	-	-	+
Crassocephalum crepidioides (Benth.) S. Moore		X	-	-	+	-	-	+
Crepis sp.		X	-	-	-	+	-	-
Dubautia scabra (DC.) Keck	Kupaoa	E	+	+	+	-	-	-
Eclipta alba (L.) Hassk.	False daisy	X	-	-	-	-	-	+
Emilia fosbergii Nicol.	Red pua-lele	X	-	+	-	+	-	+
Emilia sonchifolia (L.) Raf.	Lilac pua-lele	X	-	-	-	+	-	+
Erechtites hieracifolia (L.) Raf.	Fireweed	X	-	+	+	-	+	+
Erechtites valerianaefolia (Wolf) DC.	Fireweed	X	-	+	+	+	-	+
Erigeron bonariensis L.	Hairy horseweed, ilioha	X	-	+	+	-	+	+
Erigeron canadensis L.	Canada fleabane	X	-	+	-	-	+	+
Erigeron pusillus Nutt.	Dwarf horseweed	X	-	-	-	-	+	-
Eupatorium riparium Regel	Hamakua pamakani	X	+	+	+	-	+	+
Gnaphalium japonicum Thunb.	Cudweed	X	-	-	-	-	-	+
Gnaphalium purpureum L.	Purple cudweed	X	-	+	-	-	-	-
Lapsana communis L.	Nipplewort	X	-	-	+	-	-	-
Pluchea odorata (L.) Cass.	Pluchea, shrubby fleabane	X	+	+	+	+	+	+

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Sonchus oleraceus L.	Sow thistle, pua-lele	X	-	-	-	-	-	+
Veronia cinerea (L.) Less.	Ironweed	X	-	+	-	+	-	+
Wedelia trilobata (L.) Hitchc.	Wedelia	X	-	-	-	+	+	+
Youngia japonica (L.) DC.	Oriental hawksbeard	X	-	+	+	-	+	+
CONVOLVULACEAE								
Argyreia nervosa (Burm. f.) Bojer	Small wood rose	X	-	-	-	+	-	-
Ipomoea alba L.	Moonflower	X	-	-	-	+	+	+
Ipomoea batatas (L.) Poir.	'Uala, sweet potato	P	-	-	-	-	-	+
Ipomoea indica (Burm.) Merr.	Koali-'awahia	I	-	-	-	+	+	+
Ipomoea triloba L.	Little bell	X	-	-	-	-	+	+
Merremia aegyptia (L.) Urban	Hairy merremia, koali-kua-hulu	I	-	-	-	-	+	+
Merremia tuberosa (L.) Rendle	Wood rose	X	-	-	-	+	+	+
CRASSULACEAE								
Kalanchoe pinnata (Lam.) Pers.	Air plant, 'oliwa-ku-kahakai	X	-	-	-	+	+	-
CRUCIFERAE								
Cardamine flexuosa With. forma umbrosa (Gren. & Godr.) O. E. Schultz	Bitter cress	X	-	-	-	-	-	+
CUCURBITACEAE								
Momordica charantia L. var. pavel Crantz	Balsam apple, peria	X	-	-	-	-	+	+
EBENACEAE								
Diospyros ferrea Bakh. ssp. sandwicensis (A. DC.) Bakh.	Lama	E	-	-	+	+	+	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
EPACRIDACEAE								
Styphelia tameiameiae (Cham.) F. Muell.	Pukiawe	I	-	+	+	+	+	-
ERICACEAE								
Vaccinium calycinum Sm.	'Ohelo-kau-la'au	E	-	+	+	-	-	-
Vaccinium reticulatum Sm.	'Ohelo	E	+	+	+	-	-	-
EUPHORBIACEAE								
Aleurites moluccana (L.) Willd.	Kukui	P	-	-	+	+	-	-
Antidesma platyphyllum Mann	Hame, mehame	E	-	-	+	+	-	-
Euphorbia glomerifera (Millsp.) L. C. Wheeler		X	-	-	-	-	-	+
Euphorbia hirta L.	Garden spurge, koko-kahiki	X	-	-	-	-	-	+
Euphorbia prostrata Ait.	Prostrate spurge	X	-	-	-	-	-	+
Euphorbia thymifolia L.	Thyme-leaved spurge	X	-	-	-	-	-	+
Macaranga grandifolia (Blanco) Merr.	Bingabing	X	-	-	-	+	-	-
Macaranga tanarius (Stickm.) Muell.-Arg.		X	-	-	-	+	-	-
Manihot glaziovii Muell.-Arg.	Ceara rubber	X	-	-	-	+	-	-
Phyllanthus debilis Klein ex Willd.	Phyllanthus weed	X	-	-	-	-	+	+
Ricinus communis L.	Castor bean, koli	X	-	-	-	-	+	+
FLACOURTIACEAE								
Xylosma hawaiiense Seem. var. hillebrandii (Wawra) Sleumer	Maua	E	-	-	+	-	-	-
GESNERIACEAE								
Cyrtandra lysiosepala (Gray) C. B. Clarke		E	-	-	+	-	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Cyrtandra paludosa Gaud. var. integrifolia Hillebr.		E	-	-	+	-	-	-
Cyrtandra paludosa Gaud. var. irrostrata St. John		E	-	-	+	+	-	-
Cyrtandra platyphylla Gray		E	-	-	+	-	-	-
Cyrtandra sp. 1		E	-	-	+	-	-	-
Cyrtandra sp. 2		E	-	-	+	-	-	-
Cyrtandra sp. nov.		E	-	-	+	+	-	-
GOODENIACEAE								
Scaevola chamissoniana Gaud. var. bracteosa Hillebr.	Naupaka-kauhiwi	E	-	+	+	-	-	-
Scaevola taccada (Gaertn.) Roxb.	Naupaka-kahakai	I	-	-	-	+	-	-
GUTTIFERAE								
Calophyllum inophyllum L.	Kamani	P	-	-	-	+	-	-
Hypericum degeneri Fosb.		X	-	-	+	-	-	-
Hypericum mutilum L.	St. Johnswort	X	-	+	+	-	+	+
LABIATAE								
Coleus blumei Benth.	Coleus	X	-	-	-	+	-	-
Hyptis pectinata (L.) Poit.	Comb hyptis	X	-	+	-	+	+	+
Phyllostegia vestita Benth.	Ulihi	E	-	-	+	-	-	-
Stenogyne calaminthoides Gray		E	-	+	+	-	-	-
LAURACEAE								
Cassytha filiformis L.	Kauna'oa, kauna'oa-pehu	I	-	+	-	+	-	-
Persea americana Mill	Avocado	X	-	-	+	+	+	+
LEGUMINOSAE								
Acacia confusa Merr.	Formosa koa	X	-	-	-	+	-	-
Albizia falcataria (L.) Fosb.	Molucca albizia	X	+	-	-	+	+	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Albizia sp.		X	-	-	-	+	+	-
Caesalpinia major (Medic.) Dandy & Excell	Kakalaioa, gray nickers	I	-	-	-	-	+	-
Canavalia ensiformis (L.) DC.	Jackbean	X	-	-	-	-	-	+
Cassia alata L.	Candlebush	X	-	-	-	-	+	-
Cassia lechenaultiana DC. var. lechenaultiana	Partridge pea, lauki	X	-	+	-	+	+	+
Cassia occidentalis L.	Coffee senna, 'auko'i	X	-	-	-	-	+	+
Crotalaria berteriana DC.	Rattlebox, tawny crotalaria	X	-	-	-	-	-	+
Crotalaria incana	Fuzzy rattlepod	X	-	-	-	+	+	+
Crotalaria pallida Aiton		X	-	-	-	-	+	+
Crotalaria retusa L.	Rattlebox, sauni	X	-	-	-	-	-	+
Crotalaria spectabilis Roth	Rattlepod	X	-	-	-	-	+	+
Desmanthus virgatus L.	Virgate mimosa	X	-	-	-	-	+	+
Desmodium cajanifolium (HBK.) DC.	Tree desmodium	X	-	-	-	-	+	+
Desmodium canum (Gmel.) Schinz & Thell.	Spanish clover	X	-	-	-	-	+	+
Desmodium discolor Vogel		X	-	-	-	-	-	+
Desmodium heterophyllum (Willd.) DC.		X	-	-	-	+	+	+
Desmodium tortuosum (Sw.) DC.	Florida beggarweed	X	-	-	-	-	+	+
Desmodium triflorum (L.) DC.	Three-flowered beggarweed	X	-	+	-	-	+	+
Desmodium uncinatum (Jacq.) DC.	Spanish clover	X	-	+	+	+	+	+
Desmodium sp.		X	-	-	-	-	+	+
Indigofera suffruticosa Mill.	Indigo, 'iniko	P	-	-	-	-	+	+
Leucaena leucocephala (Lam.) de Wit	Koa-haole, ekoa	X	-	-	-	-	+	+
Mimosa pudica L. var. unijuga (Duchass. & Walp.) Griseb.	Sensitive plant, pua-hilahila	X	-	-	-	+	+	+
Mucuna gigantea (Willd.) DC.	Ka'e'e, ka'e'e'e	I	-	-	-	+	+	-
Phaseolus lathyroides L.	Cowpea	X	-	-	-	-	-	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Samanea saman (Jacq.) Merr.	Monkeypod	X	-	-	-	+	-	-
LOBELIACEAE								
Clermontia hawaiiensis (Hillebr.) Rock	'Oha-kepau	E	-	-	+	-	-	-
Clermontia parviflora Gaud. ex Gray		E	-	-	+	-	-	-
Cyanea tritomantha Gray	'Aku'aku, 'aku	E	-	-	+	-	-	-
Cyanea sp.		E	-	-	+	-	-	-
Laurentia longifolia (L.) Engl.	Star of Bethlehem	X	-	-	-	-	+	+
LOGANIACEAE								
Buddleja asiatica Lour.	Butterflybush, huelo-'ilio	X	+	+	+	+	+	+
Labordia hedyosmifolia Baill.		E	-	-	+	-	-	-
LYTHRACEAE								
Cuphea carthagensis (Jacq.) Macbride	Cuphea, puakamoli	X	-	+	+	-	+	+
Lythrum maritimum HBK.	Pukamole	X	-	-	-	-	-	+
MALVACEAE								
Hibiscus tiliaceus L.	Hau	I	-	-	-	+	-	-
Hibiscus youngianus Gaud. ex Hook. & Arn.	Hau-hele, 'akiohala	E	-	-	-	-	+	-
Malvastrum coromandelianum (L.) Garcke	False mallow	X	-	-	-	-	-	+
Malvaviscus arboreus Cav.	Turk's cap	X	-	-	-	-	-	+
Sida rhombifolia L.	Cuba jute	X	-	-	-	-	+	-
Thespesia populnea (L.) Soland. ex Correra	Milo	P	-	-	-	+	-	-

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MELASTOMATACEAE								
Clidemia hirta (L.) L. Don	Koster's curse	X	-	-	+	-	+	-
Heterocentron subtriplinervium (Link & Otto) A. Br. & Bouche	Pearl flower	X	-	+	+	-	-	-
Melastoma malabathricum L.	Malabar melastome	X	-	+	+	+	+	-
Pterolepis sp.		X	-	-	-	-	+	-
Tetrazygia bicolor (Triana) Cogn.		X	-	-	+	-	-	-
Tibouchina urvilleana (DC.) Cogn.	Lasiandra, glorybush	X	-	-	+	-	-	-
MENISPERMACEAE								
Cocculus ferrandianus Gaud.	Huehue, hue'ie	E	-	+	+	+	+	-
MORACEAE								
Artocarpus altilis (Park.) Fosb.	Breadfruit, 'ulu	P	-	-	-	+	-	-
Artocarpus heterophyllus Lam.	Jackfruit	X	-	-	+	-	-	-
Cannabis sativa L.	Marijuana, pakalolo, pot	X	-	-	+	+	-	-
Cecropia obtusifolia Sandmark	Guarumo	X	-	+	+	+	+	+
Cecropia peltata Sandmark	Trumpet tree	X	-	-	+	+	+	+
Ficus microcarpa L. f.	Chinese banyan	X	-	-	-	+	-	-
MYRSINACEAE								
Ardisia humilis Vahl	Shoebutton ardisia	X	-	-	-	+	-	-
Embelia pacifica Hillebr.	Kilioe	E	-	-	+	-	-	-
Myrsine lessertiana A. DC.	Kolea-lau-nui	E	-	+	+	-	+	-
Myrsine sandwicensis A. DC.	Kolea-lau-li'i	E	-	-	+	-	-	-
MYRTACEAE								
Melaleuca quinquenervia (Cav.) Blake	Paperbark	X	-	+	-	+	-	-

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Metrosideros collina (J. R. & G. Forst.) Gray var. glaberrima (Levl.) Rock	'Ohi'a-lehua	E	+	+	+	+	+	-
Metrosideros collina (J. R. & G. Forst.) Gray var. incana (Levl.) Rock	'Ohi'a-lehua	E	+	+	+	+	+	-
Metrosideros collina (J. R. & G. Forst.) Gray var. macrophylla Rock	'Ohi'a-lehua	E	-	+	+	+	+	-
Psidium cattleianum Sabine forma cattleianum	Strawberry guava	X	-	+	+	+	+	+
Psidium cattleianum Sabine forma lucidum Deg.	Yellow strawberry guava, waiawi	X	-	+	+	-	+	-
Psidium guajava L.	Guava, kuawa	X	-	+	+	+	+	+
Syzygium cumini (L.) Skeels.	Java plum, palama	X	-	-	-	+	+	+
Syzygium jambos L.	Rose apple, 'ohi'a-loke	X	-	+	+	+	-	-
Syzygium malaccense (L.) Merr. & Perry	'Ohi'a-'ai, mountain apple	P	-	-	-	+	-	-
Tristania conferta R. Br.	Brush box	X	-	-	-	+	-	-
NYCTAGINACEAE								
Pisonia umbellifera (J. R. & G. Forst.) Seem	Papala-kepau	I	-	-	+	-	-	-
Pisonia sp.	Papala-kepau	I	-	-	+	-	-	-
ONAGRACEAE								
Ludwigia octivalvis (Jacq.) Raven	Kamole, primrose willow	I	-	-	+	-	+	+
Ludwigia palustris (L.) Ell.	Water purselane	X	-	-	+	-	-	-
OXALIDACEAE								
Oxalis corniculata L.	Yellow wood sorrel, 'ihi	I	-	+	-	-	-	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Oxalis martiana Zucc.	Pink wood sorrel, 'ihi pehu	X	-	-	-	-	+	+
PASSIFLORACEAE								
Passiflora edulis Sims forma flavicarpa Deg.	Yellow liliko'i	X	-	+	+	+	+	+
Passiflora foetida L.	Scarlet-fruited passionflower	X	-	+	-	+	+	+
PIPERACEAE								
Peperomia cookiana C. DC.	'Ala'ala-wai-nui	E	-	-	+	-	-	-
Peperomia hypoleuca Miq. var. hypoleuca	'Ala'ala-wai-nui	E	-	-	+	+	-	-
Peperomia hypoleuca Miq. var. pluvigaudens (C. DC.) Yuncker	'Ala'ala-wai-nui	E	-	-	+	-	-	-
Peperomia latifolia Miq.	'Ala'ala-wai-nui	E	-	-	+	-	-	-
Peperomia leptostachya Hook. & Arn.	'Ala'ala-wai-nui	I	-	-	-	+	-	-
Peperomia cf. lilifolia DC.	'Ala'ala-wai-nui	E	-	-	+	-	-	-
Peperomia tetraphylla (Forst. f.) Hook. & Arn.	'Ala'ala-wai-nui	I	-	-	+	-	-	-
Peperomia sp.	'Ala'ala-wai-nui	E	-	-	+	-	-	-
Piper methysticum Forst. f.	'Awa	P	-	-	+	+	-	-
PLANTAGINACEAE								
Plantago lanceolata L.	Narrow-leaved plantain	X	-	+	-	-	-	+
Plantago major L.	Broad-leaved plantain, lau-kai	X	-	-	+	+	+	+
POLYGALACEAE								
Polygala paniculata L.	Polygala	X	-	-	-	-	+	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
POLYGONACEAE								
Polygonum capitatum Ham. ex Don	Polygonum	X	+	+	+	-	-	+
PROTEACEAE								
Grevillea robusta A. Cunn.	Silk oak, 'oka-kilika	X	-	-	-	+	-	-
Macadamia ternifolia F. Muell. var. integrifolia (Mdn. & Bet.) Mdn. & Bet.	Macadamia	X	-	-	-	-	-	+
ROSACEAE								
Rubus ellipticus Sm. var. obcordatus Focke	Yellow Himalayan raspberry	X	-	-	+	-	-	-
Rubus rosaefolius Sm.	Thimbleberry	X	-	+	+	+	+	-
RUBIACEAE								
Bobea timonioides (Hook. f.) Hillebr.	'Ahakea	E	-	-	+	-	-	-
Canthium odoratum (Forst. f.) Seem.	Alahe'e, walahe'e	I	-	-	+	+	-	-
Coffea arabica L.	Arabian coffee	X	-	-	+	+	-	-
Coprosma menziesii Gray	Pilo, kopa	E	-	+	+	-	-	-
Coprosma ochracea Oliver var. rockiana Oliver	Pilo, kopa	E	-	-	+	-	-	-
Coprosma rhyncocarpa Gray	Pilo	E	-	-	+	-	-	-
Coprosma sp.	Pilo, kopa	E	-	-	+	-	-	-
Gardenia augusta (L.) Merr.	Gardenia	X	-	-	+	-	-	-
Gardenia remyi Mann	Nanu	E	-	-	+	-	-	-
Gouldia terminalis (Hook. & Arn.) Hillebr.	Manono	E	-	-	+	-	-	-
Hedyotis centranthoides (Hook. & Arn.) Steud. forma centranthoides	Kilauea hedyotis	E	+	-	+	-	-	-
Hedyotis corymbosa (L.) Lam.		X	-	-	-	-	-	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
Morinda citrifolia L.	Noni	P	-	-	-	+	-	-
Paederia foetida L.	Maile pilau	X	-	-	+	+	+	+
Psychotria hawaiiensis (Gray) Fosb.	Kopiko	E	-	+	+	+	-	-
Richardia brasiliensis Gomez	Richardsonia	X	-	-	-	+	+	+
Spermacoce assurgens R. & P.	Buttonweed	X	-	-	-	+	+	+
Spermacoce mauritiana Gideon	Borreria	X	-	-	-	+	+	+
RUTACEAE								
Citrus limonia Osbeck	Lemon	X	-	-	+	-	-	+
Citrus sp.		X	-	-	+	-	-	+
Pelea clusiaefolia Gray var. cuneata St. John & Hume	Alani	E	-	-	+	-	-	-
Pelea radiata St. John	Alani	E	-	-	+	-	-	-
Pelea sp.		E	-	-	+	-	-	-
SAPINDACEAE								
Cardiospermum halicacabum L.	Balloon vine, 'inalua	X	-	-	-	-	+	+
SAXIFRAGACEAE								
Broussaisia arguta Gaud.	Kanawao	E	-	-	+	-	-	-
SCROPHULARIACEAE								
Castilleja arvensis Schlecht. & Cham.	Field Indian paintbrush	X	-	+	-	+	+	+
Lindernia crustacea (L.) F. Muell.	Lindernia	X	-	-	-	-	-	+
Torenia asiatica L.	Ola'a beauty, nani-o-Ola'a	X	-	-	-	-	-	+
SOLANACEAE								
Cestrum nocturnum L.	Night cestrum, 'ala-aumoe	X	-	-	-	+	+	-
Physalis peruviana L.	Cape gooseberry, poha	X	-	+	+	-	-	-
Solanum nigrum L.	Popolo, black nightshade	I	-	-	-	-	-	+

BOTANICAL NAME	COMMON NAME	STATUS	1	2	3	4	5	6
STERCULIACEAE								
Melochia umbellata (Houtt.) Stapf.	Melochia	X	-	+	-	+	+	+
Waltheria indica L. var. americana (L.) R. Br. ex Hosaka	Hi'aloa, 'uhaloa	I	-	+	-	+	-	-
THYMELAEACEAE								
Wikstroemia sandwicensis Meisn.	'Akia	E	-	+	+	+	+	-
ULMACEAE								
Trema orientalis (L.) Bl.	Gunpowder tree	X	-	+	-	+	+	+
UMBELLIFERAE								
Centella asiatica (L.) Urban	Asiatic pennywort, pohekula	X	-	-	-	-	+	+
Hydrocotyle verticillata Thunb.	Pohepohe	X	-	-	-	-	-	+
URTICACEAE								
Pipturus hawaiensis Levl.	Mamaki	E	+	+	+	+	+	+
Pipturus sp.	Mamaki	E	-	-	+	-	-	-
Touchardia latifolia Gaud.	Olona	E	-	-	+	-	-	-
Urera sandvicensis Wedd.	Opuhe	E	-	-	+	-	-	-
VERBENACEAE								
Lantana camara L.	Lantana, lakana	X	-	+	-	+	+	+
Stachytarpheta australis Mold.	Cayenne vervain	X	-	-	+	+	+	+
Stachytarpheta jamaicensis (L.) Vahl	Jamaica vervain, owi	X	-	-	-	+	+	+
Stachytarpheta urticaefolia (Salisb.) Sims	Nettle-leaved vervain	X	-	-	-	+	+	+
Verbena litoralis HBK.	Verbena, ha'uowi	X	-	+	-	+	+	+

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APPENDIX D

EFFECTS OF GEOTHERMAL DEVELOPMENT ON PROPERTY VALUES AND SALES

APPENDIX D: EFFECTS OF GEOTHERMAL DEVELOPMENT ON PROPERTY VALUES AND SALES

I. INTRODUCTION

This report contains an assessment of the probable impact which the proposed 500 MW geothermal development would have on surrounding property values and sales. The assessment is based on the impact which the Natural Energy Laboratory of Hawaii (NELH) HGP-A geothermal well (formerly operated by the University of Hawaii (UH)), and 3-MW power plant have had on surrounding property; the facility began operations in 1981. An assessment based on this operation is viewed as a worst-case scenario, even though this power plant is much smaller than the proposed plants. The reason for this is that the proposed plants, which would be long-term commercial operations rather than a short-term research project, would involve better design and control technology and would therefore produce fewer emissions, generate less noise, and be better screened from view.

Operating factors of geothermal wells and plants which could adversely affect surrounding property values and sales include:

- o hydrogen sulfide (H_2S) emissions (which have the noxious smell of rotten eggs, even though the emissions pose no health hazard at low concentrations);
- o noise from drilling, well venting, and plant operations;
- o visual impact of the plant and well field; and,
- o visual impact of steam emissions.

The potential of royalties from selling the steam beneath a property may possibly offset these factors, and this would enhance property values. Also, some properties near the geothermal operations may have commercial potential based on non electric uses of the steam or brine.

The analysis which follows involved the following:

- o a review of Multiple Listing Service (MLS) data on Puna property sales for the period 1978 to 1987;
- o a detailed review of all mid 1987 MLS data on property sales in Leilani Estates;

- a detailed review of property tax assessments of selected properties of various sizes and distances from the HGP-A well, from the time the subdivision was first developed through 1987;

- a discussion with the County tax appraiser responsible for Puna; and

- in-depth discussions with those Realtors who are the most active in the Puna area, focussing on how property values have changed, and the primary causes underlying the changes.

The analysis revealed that a great many factors unrelated to geothermal operations have affected property values and sales factors which create difficulties in using a purely statistical approach on sales and/or tax-assessment values to determine the effect which the HGP-A well and power plant have had on property values and sales. Because of these difficulties, the discussions with knowledgeable Realtors were considered to be the the most reliable.

II. GENERAL FACTORS AFFECTING PUNA PROPERTY VALUES AND SALES

In 1985, the Puna District, which is nearly the size of the Island of Oahu, had 56,992 parcels, of which 51,002 were vacant. This compares to a total of only 39,157 homes in the entire County. Most of the parcels in Puna are located in nonconforming subdivisions which lack water and electrical service and which are served by substandard paved and dirt roads. The parcels, which range in size from less than 10,000 square feet to many acres, are located in diverse areas, ranging from oceanfront locations to high-elevation rain forests.

Some parcels are within commuting distance of Hilo and other employment centers, while other parcels are relatively remote. Further, some parcels are vulnerable to being covered by lava flows while others are not. In view of this diversity of properties, factors affecting property values and sales in Puna have not had a uniform effect - some properties have increased in value while others have dropped in value during the same time period. Nevertheless, certain generalizations can be made regarding property values.

Many, but not all, Puna parcels lost value during the early and mid-1980s. Factors contributing to this include:

- high interest rates during the early 1980s;

- new tax laws passed in 1986 which reduced the speculative attraction of investment properties;

- repeated national telecasts which showed homes in Puna being destroyed by molten lava;

- withdrawal of hazard insurance on homes or increased insurance rates for many areas in Puna due to the increased activity of Kilauea and the loss of homes to lava flows;

- repeated news coverage of major marijuana raids and arrests which have contributed to the impression that Puna is a high-crime area, unsafe for families; and

- the closing of Puna Sugar Co., which increased the supply of land on the market, while removing jobs from the economy.

The net effect of these factors has been to greatly reduce the attractiveness of and the demand for parcels, while increasing the supply of land on the market. The consequence of this is lower values for many Puna properties.

III. GEOTHERMAL EFFECTS ON PROPERTY VALUES AND SALES

Among Realtors who are familiar with property sales in Puna, a near unanimous consensus exists that the HGP-A well and geothermal power plant have produced a strongly adverse affect on surrounding property values and sales. According to these Realtors, the overwhelming factor affecting property values and sales is the too-frequent emission and high level of hydrogen sulfide which has the noxious smell of rotten eggs. The occasional noise from well venting is much less of a problem, and residents have adjusted to it. Noise emitted from the wells and visual impacts of the geothermal operations are regarded as having an insignificant affect on property values and sales.

The area that is adversely affected lies within a half-mile of the HGP-A well, although estimates of the affected area ranged from 1/4 to 1 mile. Most of the affected parcels are located within the eastern portion of Leilani Estates. Outside the affected circle, the hydrogen sulfide concentrations are sufficiently low that the noxious smell does not exist, and property values and sales are not noticeably affected. For all affected properties, the general opinion is that property values are about one-half to three-quarters of what they would normally be.

The possibility of enhanced property values due to speculative buying to obtain the mineral rights to the steam beneath a property has not occurred. For most properties, these rights are retained by the State of Hawaii or by former property owners. Further, nearby property values have not been increased due to the potential commercial value of non-electric uses of the steam or brine.

It should be noted, however, that the perception by Realtors is not verified by MLS data sales activity and prices near the HGP-A plant do not appear to differ substantially from the sales activity and prices in more distant areas. Similarly, assessed property values of properties near the geothermal operation, and the time trend of these values, appear to be approximately the same as those for comparable properties at more distant locations.

IV. EXPECTED EFFECT OF THE PROPOSED DEVELOPMENT ON PROPERTY VALUES AND SALES

For the proposed geothermal power plants, the appropriate mitigating measure - one which is in fact planned - is to install control devices which would reduce hydrogen sulfide emissions to negligible levels - the smaller the emissions, the smaller the affected area. Assuming (1) a half-mile impact radius for the HGP-A plant; (2) a worst-case situation for the proposed geothermal wells and power plants of emissions equal to 10 percent of the emissions from the original HGP-A operation (prior to installation of an efficient H_2S abatement system); and (3) emission concentrations which decline in proportion to the square of the distance from each emission source; then, the area in which property values would be adversely affected would lie within about 835 feet of each emission source. Property values and sales outside these circles are unlikely to be affected adversely by the proposed geothermal operations.